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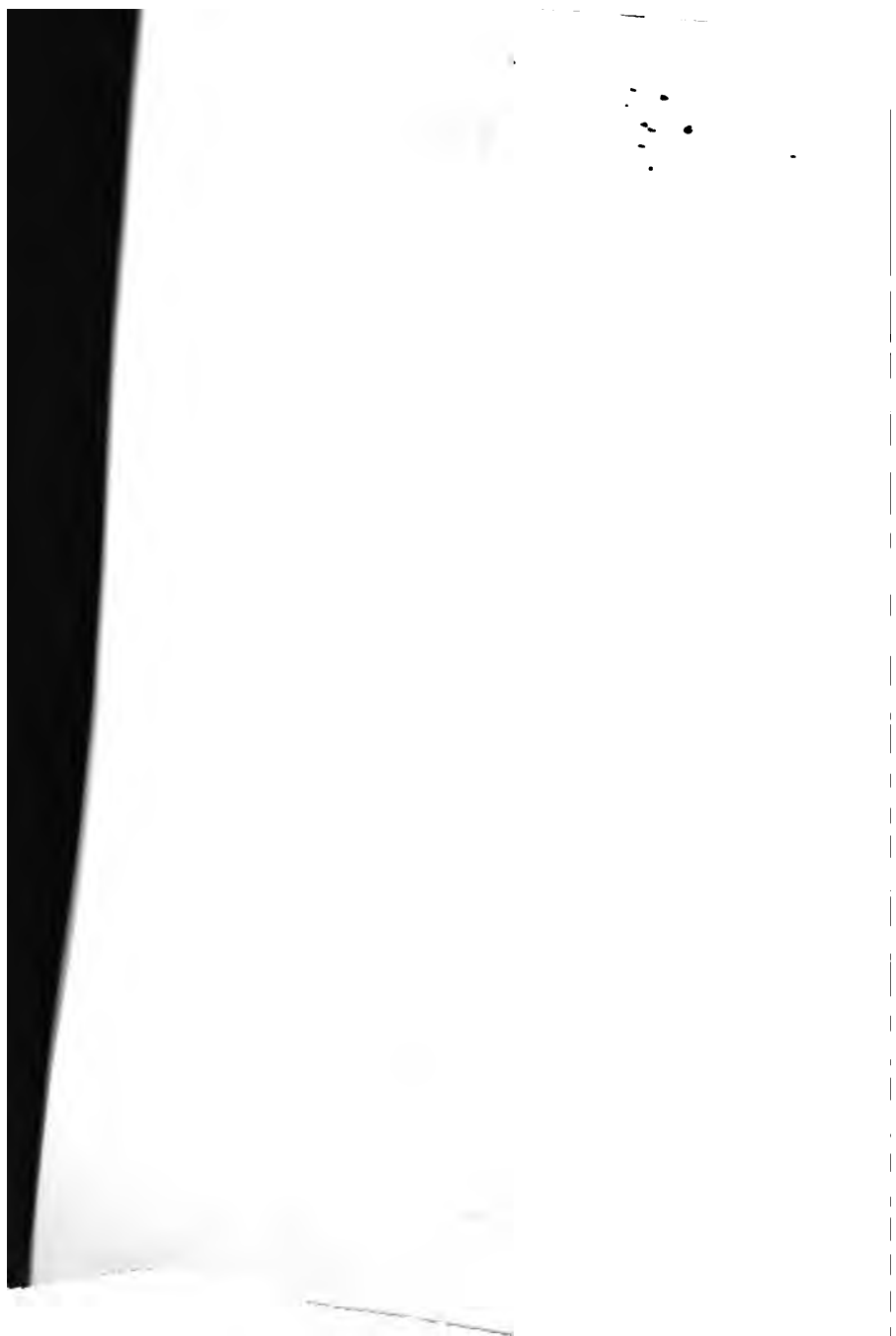
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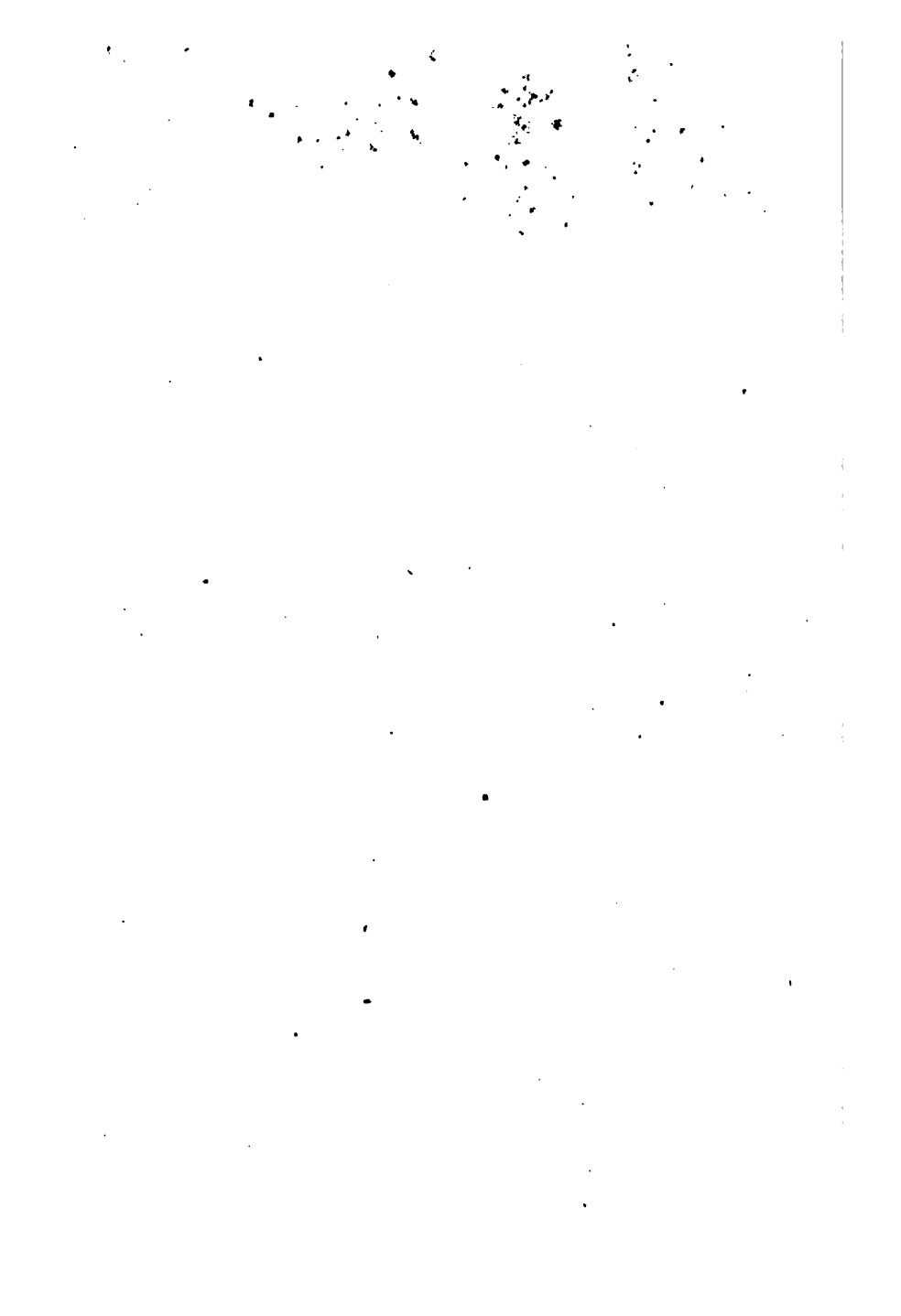




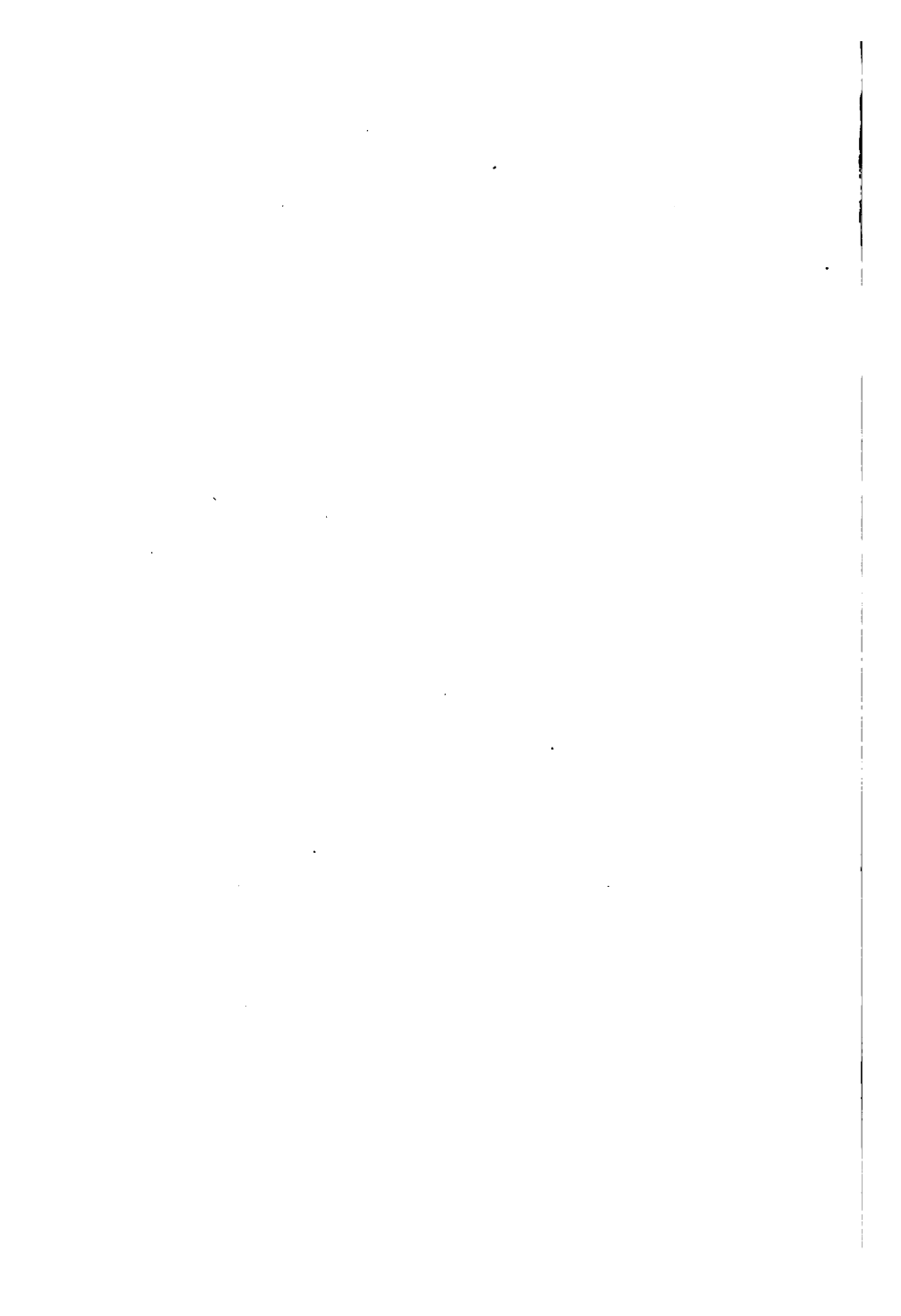
AIR AS FUEL.







AIR AS FUEL.



AIR AS FUEL;

OR,

PETROLEUM AND OTHER MINERAL OILS UTILIZED BY
CARBURETTING AIR AND RENDERING IT INFLAMMABLE.

BY

OWEN C. D. ROSS, M. INST. C.E.



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PREFACE.

ABOUT ten years since Mr. Jevons published the startling statement that the coal-fields of Great Britain would be probably exhausted, and the industrial supremacy of this country would consequently come to an end in rather more than a century from that date. This opinion was endorsed by Mr. John Stuart Mill, by whom the attention of the House of Commons and of the country was very seriously drawn to its grave significance.

Mr. Robert Hunt, the Keeper of Mining Records, founding his calculation on an average annual increase in the consumption of two-and-three-quarter millions of tons, had previously estimated that the entire quantity of available coal in these Islands down to a depth of four thousand feet, which he calculated to amount to about 80,000,000,000 tons, would be exhausted in two hundred and twelve years; but the average increase during the last ten years (1863 to 1872) has risen to no less than three-and-three-quarter millions of tons per annum, which tends to confirm Mr. Jevons' calculations; and Mr. Warrington Smyth, writing in 1866, with all the authority of President of the Geological Society, besides several other eminent writers and public speakers before him and since, have expressed their concurrence with these disquieting vaticinations. Only the most sanguine have ventured to hope that the evil day may be deferred for two or three centuries.

Finally, in the second edition of his book, Mr. Jevons

supported his own belief in the non-existence of any other available fuel but coal, by quotations from a letter of Professor Tyndall's, in which he asserted very positively that he could see "no prospect of any substitute being found for coal as a source of motive power."

These views have taken deep root in the minds of many reflecting men, but it may be inferred from the statements contained in the following pages that there exists at least one widely diffused source of an important auxiliary fuel. Wishing to confine myself entirely to facts which can easily be verified, I have attempted no estimate of the amount of bituminous shales and clays, &c., which are in this country available for the production of oil, but that they do exist in sufficient quantities to assist materially in deferring the exhaustion of our coal-fields, if ever oil should be generally adopted for "carburetting air," there can be no reasonable doubt, and even the much despised oil-yielding Kimmeridge clay (of which a mass exists 700 feet in thickness throughout the greater part of the southern counties of England) may possibly play its part before "the evil day" arrives. Again, coal, it is true, will not bear much cost of freight or transport; but if one ton of mineral oil can be made to do the duty of four or five tons of coal, it will also bear four or five times as much expense of carriage; and British enterprise, which already seeks ores of iron and manganese, copper and pyrites in ever-increasing quantities on the shores of foreign countries, may some day find it also conducive to the industrial prosperity of England largely to increase the importation of foreign oils for use as fuel.

If we carry our memories back a few years, how long is it since it would have appeared incredible and most alarming

to have foretold that in the year 1873 the value of the importations from abroad of six such indispensable articles of food as corn, sugar, tea, coffee, butter, and cheese would exceed 102 millions sterling? Now, however, that the reality is before us, we regard it with totally different feelings. If, indeed, from the value of the Imports of 1873 that sum were struck off, it would reduce the total to £269,000,000, as against £311,000,000 of Exports, which figures, placed side by side, it must be admitted would show a very unsatisfactory, if not impossible, Balance of Trade; and they undoubtedly betoken the somewhat singular anomaly that the present prosperity of our foreign commerce, and consequently also of our native industry, is dependent in a great measure on the necessity of importing from foreign countries a large part of our chief articles of food.

The day will perhaps come when Englishmen will be accustomed to regard as equally advantageous a very large importation of "raw material" in the shape of foreign fuel, with which to balance the shipments and sale of the concurrently increasing and much more remunerative articles manufactured in the United Kingdom for foreign consumption.

It is, however, with the utmost diffidence that I venture to indicate the adoption of "Air as Fuel" as likely materially to affect so large a question.

O. C. D. R.

LONDON, *Nov.* 13, 1874.

TABLE OF CONTENTS.

I.—THE UTILIZATION OF LIQUID FUEL AS HITHERTO EFFECTED.

	PAGE
Experiments with Petroleum in France	1
Experiments with Petroleum and Creosote at Woolwich	2
Production of Petroleum in America, &c.	4
Production of Bituminous Shale Oil	5

II.—PRINCIPLES WHICH REGULATE THE ECONOMY OF FUEL.

Measurement of Heat	7
Calorific Power of Fuel	7
Evaporative Power of Fuel	7
Elementary Constituents of Fuel	8
Thermal Effect of Fuel, or the Intensity of Heat in a Furnace ..	9
Thermal Effect when Fuel is burnt with exactly the corresponding Quantity of Air	10
Thermal Effect when Fuel is burnt with double the corresponding Quantity of Air	11
Excessive Volume of Air ordinarily used for promoting the Com- bustion of Coal, and consequent Waste of Heat	12
Burning Air	14
Description of the Process now advocated for Utilizing Liquid Fuel	16
Complete Conversion of Mineral Oils into Vapour or Gas	17
Calculation of the Quantity of Vapour obtainable at different Temperatures	18
The Air need not be wholly saturated with Vapour	19
When the Vapour is of the proper degree of density, 260,636 cubic feet of Inflammable Air are obtainable from 1 ton of Petroleum	20

III.—SUPERIORITY IN CALORIFIC POWER AND IN THERMAL EFFECT OF PETROLEUM AND OTHER HYDROCARBON LIQUIDS OVER COAL.

	PAGE
Complete Combustion obtainable with Air carburetted as described	21
Evaporative Power of Petroleum	21
Waste of Heat in high-temperature Furnaces	22
Waste of Heat occasioned by the low Thermal Effect obtainable with Coal	23
Increased Thermal Effect obtainable in a Furnace by using Carburetted Air	23
Mr. Menelaus' Opinion of the Advantages of Gas as Fuel	24
Professor Macquorn Rankine on the Advantages of Liquid Fuel ..	25
Siemens' "Regenerative" Furnace	28
The "Acme of Perfection" in a Furnace	29

IV.—SPECIAL APPLICATIONS OF CARBURETTED AIR.

Application to Metallurgical Purposes	31
Application to Ocean Steamships	31
Application to Ships of the Navy	33
Superiority of Carburetted Air for obtaining Regulated Tempera- tures	33
Obtaining Sulphur Flour direct from the Ores by the use of Car- buretted Air	34
Application of Carburetted Air to ordinary Household Purposes, &c.	35
Hock's Petroleum Motor	36
Fogarty's Machine for Making Petroleum Gas	36
Description of the Carburetting Vessel used by the Author	37

V.—UTILIZATION OF PETROLEUM AND OTHER MINERAL OILS FOR ILLUMINATING GAS.

Mansfield's Process	39
Improvements on Mansfield's Process	40
Cooling Effects of Evaporation	40
Gas obtained from Paraffin Oil by a Hot Process	41

	PAGE
A Medium Temperature necessary	41
Quantity of Illuminating Gas obtainable from 1 ton of Petroleum Spirit	43
Composition of Coal Gas	44
The Quantity of Carbon contained in Carburetted Air is greater than in Coal Gas	45
The "Permanency" of Carburetted Air scientifically demonstrated	46
A Comparison between Coal Gas and Carburetted Air establishes the superiority of the latter	52
Economy of Carburetted Air for Country Mansions, Factories, Churches, Railway Stations and Carriages, Ocean Steamers, &c.	53
The Use of Carburetted Air is free from Danger	53
 VI.—RECAPITULATION	 57
 OBSERVATIONS ON THE RECENT GUNPOWDER EXPLOSION ON THE REGENT'S CANAL	 59
 TABLE A.	 62
TABLE B.	63

AIR AS FUEL.

I.—THE UTILIZATION OF LIQUID FUEL.

A FEW years ago, when the vast abundance of petroleum found in Pennsylvania was beginning to attract the attention of people in Europe, considerable efforts were made to utilize it for heating purposes, amongst the most noticeable of which were those which were undertaken in France, at the instigation of the Emperor Napoleon. He had seen at the laboratory of the Ecole Normale an ingenious apparatus, invented by M. Andouin, for burning petroleum and other mineral oils, and ordered M. Sainte-Claire Deville to commence a series of analyses of these oils, and to study their application to the generation of steam, especially for the purpose of marine boilers. M. Sainte-Claire Deville thereupon made a most interesting examination of the subject, the results of which are published in the Journal of the French Académie des Sciences for the years 1868 and 1869. In these papers may be read a description of furnaces by means of which liquid fuel was applied, to a certain extent successfully, to two locomotives on the Paris and Strasbourg Railway, and also to the Imperial yacht 'La Puebla.' Experiments with petroleum in France.

In the case of the steam yacht, the oil was made to trickle slowly through a number of small holes on to

a hot metal floor, at the back of which was an upright plate, pierced also with holes, to admit currents of air to support the combustion; while in the case of the locomotive engines, the oil was contained in a sort of gridiron pierced with a great number of holes, placed horizontally in the fire-box; and in both cases it appears that the oil was burnt in the state of liquid, with probably a very insufficient combination of the vapours with atmospheric air.

The average consumption of oil with engines weighing about 20 tons, and performing the ordinary service of the line between Paris and Epernay (90 miles), with maximum gradients of 1 in 200, was at the rate of from 10 lbs. to 16 lbs. per English mile, and the evaporation of water amounted to no more than 11 lbs. per lb. of fuel. It is stated that at times a great deal of smoke was occasioned; and after repeating the experiments during two successive years and running about 1600 miles, they were discontinued. Messrs. Sainte-Claire Deville and Dieudonné, when reporting the results to the Académie des Sciences, were obliged to acknowledge that at the price at which petroleum then stood it could not advantageously compete with coal.

Experiments with petroleum and creosote at Woolwich.

Previous to this, attention had already been called to the same subject in England, and in 1865 and several following years papers were read at the Royal United Service Institution, advocating the employment of mineral oils, and especially creosote, as steam fuel for the Navy. With that view trials were made at Woolwich in 1866 and 1867 with several kinds of liquid fuel, but the general impression which resulted from them was less favourable than had been antici-

pated. In these trials, steam jets were employed with the liquid fuel to produce a blast in the furnace, and thus facilitate the combustion of the oil by converting it into a fine jet of spray; but the report afterwards made by Mr. Lloyd, the engineer-in-chief to the Navy, shows that in most of the trials much smoke was produced, and the tubes of the boiler were rendered very foul by deposition of soot in them, the necessary consequence of which was that the evaporative effects were in most instances far below what might have been expected from theoretical considerations based upon the chemical composition of the oils. The average result of the whole of the experiments was an evaporation of 13·2 lbs. of water per lb. of oil consumed, and the range of variation was from 7·14 to 18·88 lbs., as against 8 lbs. which was obtained at the same time from the combustion of 1 lb. of coal.

In point of economy it was not found that in this country mineral oils, used in the way then attempted, could at that time advantageously compete with coal. For a short time creosote, or dead earth oil, which is the refuse produce of the distillation of tar, was, it is true, adopted as a fuel by a number of manufacturers, and especially by the tar distillers, many of whom still continue to use it; but in consequence of the large demand for it which this created, the price soon ran up from $\frac{3}{4}d.$ to $4d.$ and even $6d.$ per gallon; and this, together with the large quantity of smoke which it occasions, appears to have acted as a decisive check on its general employment. It was, however, at that time asserted that the annual production of creosote in England amounted to about 100,000 tons, and that

1 ton of that substance, when used in combination with a steam blast, would do the work of from $2\frac{1}{2}$ to 3 tons of coal, and could be made to evaporate as much as nineteen times its own weight of water.

It is not to creosote, however, but to the use of bituminous shale oils, and especially of petroleum, that it is intended to draw particular attention in these pages, and it is proposed to show the great advantages which may be derived from using them in the state of vapour, combined mechanically with air by means of an apparatus of a very simple and inexpensive description.

Production
of petro-
leum in
America.

The first petroleum well was sunk in America as recently as the year 1858. In June, 1860, the product of all the wells in Pennsylvania was about 200 barrels a day; in 1862 the exports from the United States amounted to 10,523,751 gallons, and in 1864 it had risen to 31,000,000. Since that date new discoveries have been constantly made, and the demand for it has simultaneously increased. By 1872 the annual production of the United States exceeded 260,000,000 gallons, of which about one-half was exported to Europe. At the commencement of the year 1873 a new district was discovered in Pennsylvania, which was stated to have added to the previous supply at the rate of 120,000 gallons per day, and the quantity imported into England from the United States during the early months of this present year (1874) was more than four times as much as during the same period in 1873.

The price has concurrently fallen from about 24*l.* per ton, at which it stood at the time when the experiments were being made at Woolwich in 1866, to 9*l.*, which is the present price in England of petroleum

once distilled ; and this quality is now quoted at New York at $11\frac{1}{2}$ cents currency, or $5\frac{1}{4}d.$ per gallon, which is equivalent to about 6*l.* 2*s.* 6*d.* per ton ; whilst the lighter qualities fetch even less, and the crude petroleum at the wells is obtainable for about half that price. The extraction of petroleum from the wells is now effected at a less cost than the raising of coal : notwithstanding the peculiarly adverse circumstance of having to seek it at very considerable depths below the surface, new deposits are being constantly discovered, not only in the United States, but also in South America, in Asia, and in many parts of Europe, and there is every reason to expect that an increased demand for it would only have the effect of still further reducing its price by stimulating its discovery in other new districts nearer home.

The distillation of oil from coal and other bituminous minerals has also been greatly extended during the last five or six years. Linlithgowshire, Lanarkshire, and North Wales were, in the early days of this industry, the chief places where it was manufactured, and it is estimated that in the Scotch works alone, not less than 800,000 tons of shale are annually put into the retorts, yielding crude oil at the average rate of 31 gallons per ton of shale, and at a cost of about $3\frac{1}{2}d.$ per gallon ; but now it may be said to have sprung up, not only in nearly every coal-mining district of Great Britain, but also in almost every country of continental Europe, South America, and Western Asia. Vast deposits of a very rich bitumen have been discovered in France, Russia, Italy, Bohemia, Spain, the West Indies, Turkey, Palestine, and Brazil, and are

Production
of bitumi-
nous shale
oil.

now being developed for the production of oil ; these deposits extend over many thousands of square miles, the bitumen varying from 10 to 80 or 100 feet in depth, and, when properly treated, yielding, at very small cost, from 60 to 120 gallons of oil per ton of mineral.

Coal, since the date at which the experiments with liquid fuel were made at Woolwich, having enormously increased in price, and petroleum and shale oil having in a still greater proportion fallen in price, while they are now obtainable in incalculable abundance, the comparison between the two species of fuel no longer stands as it did in 1866 ; and if to this circumstance there can be added a great improvement in the method of utilizing the liquid fuel, no doubt the economy must be found now, for many purposes, on the side of the oil.

It may be mentioned that the following results can be relied upon :

1. The intrinsic calorific power of such oils for evaporative or steam purposes is several times greater than that of coal ;

2. The thermal effect, or intensity of heat obtainable from them in metallurgical operations requiring very high temperatures, is still more favourable, and allows the *efficiency* of furnaces requiring such temperatures to be many times multiplied ;

3. Illuminating gas of very superior quality may be obtained from them at much less cost and with much greater convenience than from coal.

With the object of proving these three points, it will be advisable to recall in a few words the scientific principles which regulate the economy of fuel.

II.—PRINCIPLES WHICH REGULATE THE ECONOMY OF FUEL.

It is customary to express fixed quantities of heat by reducing them to a standard *unit*, which in this country is that quantity of heat which raises the temperature of 1 lb. of water by 1° of Fahrenheit's scale; and in countries where the Centigrade thermometer and the metrical scale are used, the unit represents the quantity of heat requisite to raise the temperature of 1 kilogramme of water by 1° Centigrade. One such *metrical unit* of heat is equal to 3.96832 British units. Throughout the following calculations the British unit is the one referred to.

The quantity of heat necessary to raise the temperature of 1 lb. of water from freezing to boiling point is therefore 180 units; and provided that the feed water of a boiler is supplied to it at boiling temperature, 990 units, or five and a half times as much, are required to evaporate and convert the same weight of water into steam. This figure being a constant quantity, is sometimes, for convenience, called the *unit of evaporation*.

All combustible substances differ in the amount of their heating or *calorific power*, and this difference is expressed by the number of units generated by the combustion of 1 lb. or 1 kilogramme of such substances. Again, by dividing the calorific power in heat-units by the unit of evaporation (990), we get what is called the *evaporative power* of the fuel, viz. the number of times its own weight of boiling water that it would convert

into steam, supposing that there were no loss or waste of heating power during the combustion.

For all ordinary purposes a mass of information already exists, showing the number of units of heat ascertained by experiment to be contained in different kinds of fuel. When necessary, the theoretical heating power of a given fuel may be determined by ascertaining by chemical analysis the elements of which it is composed, and by adding together the calorific power in heat-units corresponding to those elements.

Elemen-
tary con-
stituents
of fuel.

The chief elementary constituents of all fuel being carbon and hydrogen, the process of combustion consists in the chemical combination of those two elements with certain fixed quantities of oxygen. Perfect combustion is obtained when one part by weight of carbon combines with $2\frac{3}{8}$ parts by weight of oxygen, and forms carbonic acid; or when one part by weight of hydrogen unites with 8 parts by weight of oxygen, and forms water or steam.

If the combustible portion of the fuel consists of carbon only, as in the case of coke or charcoal, the percentage of carbon in the fuel expresses its calorific power as compared with 100 parts of pure carbon. If the fuel contains both carbon and hydrogen, as, for example, petroleum and mineral oils, its relative calorific power is found by adding together the number of heat-units corresponding to the percentage amount of each of those elements contained in the fuel. When, however, as in coal, wood, peat, &c., the fuel contains, besides carbon and hydrogen, more or less oxygen, its heating power will be diminished by just such a quantity of carbon or hydrogen as would combine with the

oxygen during combustion; and in such cases it is only the surplus carbon and hydrogen, over and above the quantity equivalent to the oxygen contained in the fuel, that can generate heat. Consequently, the greater the amount of oxygen in fuel, the smaller will be its relative calorific power.

The *thermal effect* of fuel, or the temperature of the fire in a furnace, does not depend only on the calorific power or the amount of heat generated by its combustion, but also on the quantity and nature of the products resulting from the combustion, throughout the whole of which the heat which is generated distributes itself. Thermal effect of fuel.

For example, if pure solid carbon were burnt in pure oxygen, 1 lb. of carbon would combine with 2·67 lbs. of oxygen, and produce 3·67 lbs. of carbonic acid, and the quantity of heat so generated would be capable of raising the temperature of 14,544 lbs. of water 1° of Fahrenheit's scale, or of raising the temperature of 1 lb. of water 14,544° Fahr.

The specific heat of water, or its capacity for heat, is much greater than that of carbonic acid, being in the proportion of 1 to 0·2164; and therefore the increase of temperature in the carbonic acid produced by the combustion is greater than that which would be communicated to the water, in the proportion of 1 to $0·2164 \times 3·67$, or 1:0·794. Consequently, the increase of temperature in the 3·67 parts of carbonic acid to which the heat generated by the combustion of 1 part of carbon in oxygen would be communicated at the moment of combustion, may be found by dividing the number of heat-units by the quantity of heat

which raises the temperature of the 3·67 parts of carbonic acid 1 degree, i. e. by 0·794, and thus we obtain $\frac{14544}{0\cdot794} = 18,317^{\circ}$ Fahr. as the thermal effect of

carbon, or the temperature to which the 3·67 lbs. of carbonic acid might be raised. On the other hand, the thermal effect of hydrogen when burnt in pure oxygen is only 12,475° Fahr., or very much less than its calorific power, owing to its requiring for combustion eight times its weight of oxygen, and the products of combustion through which the heat is diffused being in consequence nearly two and a half times as much as in the combustion of an equal weight of carbon, and also because a large portion of the heat becomes latent by the creation of steam.

Thermal
effect when
fuel is
burnt with
the exactly
correspond-
ing quan-
tity of air.

But in all cases of the practical application of fuel, the oxygen required for combustion cannot be supplied otherwise than in the form of atmospheric air, in which it is combined with a diluent in the form of nitrogen in the proportion of 23 of oxygen to 77 of nitrogen, so that the products of combustion are very much greater than would be the case if pure oxygen only were used. The total heat which is generated by the combustion is spread over the whole of those products, and thus the thermal effect is proportionately reduced.

If it were possible to obtain perfect combustion by introducing precisely that quantity of air to the furnace which holds the requisite proportion of oxygen to supply 2·67 times the weight of available carbon and eight times the weight of available hydrogen, then, as the quantity of nitrogen in air containing 2·67 parts by weight of oxygen is 8·94, and the quantity of

nitrogen in air containing 8 parts by weight of oxygen is 26·78, it follows that the products from the combustion of 1 part by weight of carbon would be increased from 3·67 to 12·61 parts, and those from the combustion of 1 part by weight of hydrogen from 9 to 35·78 parts; and the thermal effect of the fuel, or the increase of temperature of the fire (the specific heat of nitrogen being 0·244), would be reduced to 4919° Fahr. for carbon, and 4965° Fahr. for hydrogen.

These figures again are greatly in excess of the thermal effect obtainable in practice from the combustion of coal, for the quantity of air which must necessarily pass through an ordinary boiler furnace in order to supply the requisite oxygen, as well as to keep up a sufficient draught so as to remove the gaseous products of combustion, has been found practically to amount to twice as much as that which contains the precise quantity of oxygen requisite for the complete combustion of carbon to carbonic acid, and of hydrogen to water. The amount of caloric produced by combustion in such a furnace has therefore to be spread over nearly double the above-named products, and the corresponding temperatures are thus again reduced respectively to 2566° Fahr. and 2790° Fahr.

Thermal effect when fuel is burnt with double the quantity of air.

We arrive, then, at this conclusion, that when the combustion of coal is effected by means of a draught of atmospheric air, not only is its calorific power greatly diminished by losses due to the current of imperfectly-consumed but highly-heated gases and uncombined air escaping up the furnace chimney, but also the temperature of the furnace is by this means so much reduced as to be quite inadequate for economically

effecting some of the most important metallurgical operations.*

Excessive
volume of
air ordi-
narily used
for the
combustion
of coal, and
consequent
waste of
heat.

We usually undertake, notwithstanding, to accomplish the combustion of this dense and hard fuel by heaping it in masses and then drawing or driving a volume of air over or through it of no less than from 820 to 880 cubic feet per pound, or say 730,000 cubic feet per ton of coal, in order that this air may part with such portions of the oxygen it contains as may happen to come in contact with the corresponding particles of gaseous carbon and hydrogen during its rapid course from the fire-grate to the chimney. The heat which is expended in raising the temperature of this large quantity of air from say 62° Fahr. at which it enters the fire-box, to 600° at which it escapes through the chimney of a boiler furnace, is just so much abstracted from the efficiency of the furnace. In fact the 320 cubic feet of air ordinarily employed in practice for the combustion of each pound of coal, absorb and carry off $24 \times 0.288 = 5.712$ units of heat for each degree by which their temperature is raised, or, if leaving the boiler at 600° Fahr., $5.712 \times 538 = 3073$ units per pound of coal consumed, and thus one quarter of the

* "In an ordinary furnace welding heat can only be speedily obtained by resorting to the combustion of iron, which the puddler gets by putting a clean flame on, which means that he admits free oxygen into the furnace. . . . The puddler burns from 15 to 20 per cent. of the total amount of iron he has in the ordinary furnace in order to obtain welding heat when he lets in oxygen."—Mr. C. W. Siemens' reply before the Royal Commission on the "Causes of Waste in the Combustion of Coal."

According to Pouillet, the melting point of English wrought iron (hammered) is 2910° Fahr.; of French wrought iron (soft), 2730°; of steel, 2370° to 2550°; of grey cast iron, 2010° to 2190°; of white cast iron, 1920° to 2010° Fahr.

whole theoretical, and more nearly half of the practical calorific power of the fuel is expended in heating the draught, which is equivalent to saying that the air supplied in the ordinary manner to a boiler furnace will have cost—or, to speak more accurately, will have occasioned an expenditure in heat or in money equal to the cost of heating the boiler itself. If air is admitted to a furnace in excess of this quantity, as is very generally the case, or if it leaves the furnace at a higher temperature, as happens in metallurgical operations, the loss of heat is even greater; and when, on the other hand, too little air is supplied to the fire, the result is that not only a large part of the carbon contained in the fuel is wasted in smoke, but a great loss also arises from the formation of carbonic oxide, the calorific power of which is only 4453 units, instead of carbonic acid with a calorific power of 14,544 units.*

* The following extract from Professor W. J. Macquorn Rankine's paper "On the Economy of Fuel, comprising Mineral Oils," elucidates the effect of burning carbon with too limited a supply of air, as well as some other results obtainable from the combustion of carbon.

"It is known to chemists that carbon combines in two different proportions with oxygen. One part of carbon, by weight, combined with one part and one-third of oxygen produces carbonic oxide. Carbonic oxide is itself a combustible gas, and in burning it combines with just as much additional oxygen as it already contains, so as to form carbonic acid. If we have a furnace ill supplied with air, so that the carbon only gets half the quantity of oxygen that it needs in order to form carbonic acid, then we have carbonic oxide as the product. Each pound of carbon takes up $1\frac{1}{2}$ lb. of oxygen, and to supply that oxygen 6 lbs. of air are required. The total evaporative power is diminished not merely to one-half, but to a great deal less than one-half: it is only $4\frac{1}{2}$, or three-tenths of 15, which is the total evaporative power with a full supply of oxygen.

"If we next take that carbonic oxide, the weight of which will be $2\frac{1}{2}$ lbs., namely, 1 of carbon and $1\frac{1}{2}$ of oxygen, and burn it, it

It has been well observed that the important question of "how to evaporate the greatest weight of water with a given weight of fuel," is, for all practical purposes, synonymous with the question, "how to admit the right quantity of air to the furnace in which it has to be consumed."

Burning
air.

The above figures conclusively show, that although it is customary to regard the act of combustion as one in which the principal fuel burnt is that which we

takes an additional $1\frac{1}{2}$ lb. of oxygen to burn it; and we then get exactly the quantity of heat necessary to make up the deficiency, namely, $10\frac{1}{2}$. The $4\frac{1}{2}$ units of evaporation during the first process and the $10\frac{1}{2}$ during the second, give 15 in all, making up the whole evaporative power of carbon with a full supply of oxygen.

"A conclusion can be drawn from this, which I will now explain. It is to be observed that in both those stages of the combustion of carbon we have the very same thing happening chemically; we have $1\frac{1}{2}$ lb. of oxygen combining with 1 lb. of carbon. But there is this difference in the two stages. In the first stage, where the carbonic oxide is produced from solid carbon, the solid carbon has to be converted from the solid state to a state of vapour or of gas. In the second stage we have the carbon already in the state of gas. Hence it appears that the cause of difference between the $4\frac{1}{2}$ units of evaporation due to the first stage, and the $10\frac{1}{2}$ due to the second stage of the combustion, must be that during the first stage, 6 units of evaporation disappear in transforming the carbon from the solid to the gaseous condition: in other words, the *latent heat of evaporation of carbon is six times that of water*. Thus we arrive at the conclusion that the total evaporative power of pure gaseous carbon is 21, from which if we subtract 6, the latent heat of evaporation of carbon, there remains 15, the total evaporative power of solid carbon.

"This is a theoretical inference, which has not been directly verified by experiment, but only deduced by reasoning. Still it seems to me that there can be little doubt of its truth.

"If we could get pure carbon from any natural source in the gaseous state, we should have 21 units of evaporation by burning it, because we should save the 6 units that are employed to transform the carbon from the solid to the gaseous state; that is, those 6 units would be available for the evaporation of water."—'Journal of the Royal United Service Institution,' vol. xi.

have perceptibly before our eyes in the form of coals, wood, peat, or charcoal, &c., the truth is that combustion is maintained by comparatively small quantities of carbon and hydrogen derived from the visible fuel. These are combined with a far larger quantity of diluted oxygen supplied to the fire by the air or draught, which, only because it is in a form invisible to our eyes and apparently costs nothing, is often too little considered when treating questions connected with the economy of fuel; and I venture to hazard the suggestion, that if we were accustomed to speak of the process of combustion as one in which air is the principal and carbon or hydrogen only the auxiliary element—if we were to say that we burn air instead of saying that we burn wood or coal—it would not only be equally accurate, but such a definition would be found to lead to a clearer and more easy comprehension of the conditions under which heat can be most advantageously obtained. It would then be manifest that this must depend almost entirely on the answer to the question of *how air can be most economically carburetted*. Taking this view of combustion, and commencing by the consideration of the elements of which fuel is composed, we shall see that the harder a fuel is, the greater is the quantity of heat expended in overcoming the attraction of the particles of carbon for each other; and it has been shown by Professor M. Rankine that whereas carbon in the form of diamond would give far less heat than coal, on the other hand, if we could get pure carbon from any natural source in the gaseous state, we should be able to save the heat employed in transforming it from the solid to the gaseous state, and

utilize that additional heat. Mr. Rankine has proved that by this means nearly 50 per cent. additional evaporative power would be obtained from the combustion of carbon.

Description of the process now advocated for utilizing liquid fuel.

All mineral oils are comparatively speaking pure hydrocarbons, free from sulphur, and also from the ordinary impurities which occasion ash when coal, peat, or wood is burnt, and generally devoid also of the oxygen which forms a part of the composition of all solid fuel and diminishes its calorific power. They are susceptible of being as completely converted into vapour as water itself; and although it is generally believed by chemists that carbon has never been and cannot be separately vaporized, the process about to be described furnishes the nearest approach to it, for it consists in gradually converting the oil into a thin vapour of mixed carbon and hydrogen, and therewith impregnating atmospheric air so that it shall enter the furnace already sufficiently combined with gaseous carbon and hydrogen to be immediately and by itself inflammable.*

* "*Combustibility* is not a quality of the combustible, taken by itself. It is the union of the combustible with *oxygen*, which for this reason is called the 'supporter of combustion'; neither, however, when taken alone, can be consumed.

"To effect combustion, then, we must have a combustible and a supporter of combustion. Strictly speaking, combustion means *union*; but it means *chemical* union.

"Effective combustion, for practical purposes, is in truth a question more as regards *the air* than the *gas*. We have no control over the gas, after having thrown the coal into the furnace, though we can exercise a control over the air, in all the essentials to perfect combustion. It is this which has done so much for the perfection of the *lamp*, and may be made equally available for the *furnace*; yet, strange to say, in an age when chemical science is so advanced, and in a matter so purely chemical, this is precisely what

Now it is not by any means necessary to heat the oil to the point of ebullition in order to obtain such a vapour as is required, but on the contrary a very slight degree of heat is sufficient. Indeed, when heated to the temperature of ebullition, the vapour is too dense for economical use as fuel, and inevitably occasions smoke, which circumstance may easily account for the failure in the trials at Woolwich previously recorded. Even coal gas is much too highly carburetted to be available in its ordinary condition for heating purposes, and it is a fact with which we are all familiar, that when so used, the addition of a Bunsen burner is required in order to increase the supply of air previous to combustion, and so to prevent a considerable loss of its calorific power arising from unconsumed carbon.

In order then properly to carburet air for use as fuel, a very thin vapour, the density of which should not exceed from 4 to 5 per cent. of its full density at the boiling point of the liquid, is all that is required, and this can be obtained by passing a current of air over the surface of the oil, more or less rapidly, and over more or less extent of surface. The air, when it is thus mechanically mixed with the right proportion of vapour so taken up, will burn with a blue flame of

is least attended to in practice. The how and the when and the where this controlling influence over the admission and action of the air is to be exercised, are points demanding the most serious consideration, and can only be decided on *strict chemical principles*." —'On the Combustion of Coal and the Prevention of Smoke.' By C. Wye Williams, A. Inst. C. E.

"The diffusion as much as possible of the atmospheric air and inflammable gases *prior* to combustion is a rule which science and experience alike dictate."—*Idem*. Letter from Dr. Brett to Mr. C. Wye Williams.

intense heat, similar in appearance to the flame of a blow-pipe. The lightest portions of petroleum will, even at temperatures far below the freezing point of water, supply, if confined in a closed vessel, more than sufficient vapour to carburet the air and render it inflammable. The heavier portions of the oil will require a higher temperature in order to produce the same result, so that some oils with high boiling points must be slightly heated artificially in order that they may give off a sufficiency of vapour to mix with the air.

Calculation
of the
quantity of
vapour ob-
tainable at
different
tempera-
tures.

The quantity of vapour obtainable at different temperatures is subject to known laws and can be calculated with tolerable accuracy, and it is important, by means of an example, to illustrate how this may be done.

In accordance with a law first enunciated by Dalton, the tension of the vapours of all liquids is the same at temperatures equally removed from their respective boiling points, and although this is not invariably correct, it is sufficiently so for our present purpose.

Now the boiling point of the lightest petroleum spirit which is practically applicable to the carburetting of air is 126° Fahr., and the tension at 32° Fahr. of the vapour of this spirit must therefore be approximately equal to the tension of water vapour at 94° below 212° Fahr., that is to say, at 118° Fahr., which, by reference to the published Tables of the tension of water vapour, may be seen to be 3.241 inches. Comparing this with 29.92 inches, which is the tension of both water vapour and of the petroleum vapour at their respective boiling points, it will be seen that it repre-

sents $\frac{3.241}{29.920}$, or 10.83 per cent., and this proportionate

quantity of the vapour which would be obtained from the liquid on ebullition, the specific gravity of which has been ascertained by experiment to be 2.85 (air being 1.00), is the maximum quantity of vapour which will be evaporated and may be absorbed by a given volume of air at the temperature of 32° Fahr. The specific gravity of the vapour at this temperature being $2.85 \times 0.1083 = 0.30865$ by comparison with air, it follows that, as 1 lb. of air at 32° Fahr. is equal to 12.39 cubic feet, the volume of vapour from 1 lb. of spirit would at the same temperature be 40.14 cubic feet, and following the laws which regulate the diffusion of gases, would occupy precisely the same space when absorbed by air as if it were in a vacuum, so that it would enter into and fully saturate 40.14 cubic feet of dry air.

The vapour from 1 gallon or 6.55 lbs. of this spirit would therefore saturate $40.14 \times 6.55 = 262.92$ cubic feet of air, and 1 ton of the same quality of petroleum is capable of saturating 89,914 cubic feet of dry air at 32° Fahr.

It is not, however, necessary or even advisable when using the spirit as fuel to saturate the air with the maximum amount of vapour that it could contain, but on the contrary to limit the quantity to no more than is necessary in order to obtain a gas which shall burn without any deposition of carbon, and with this view we will proceed to show that more than 700 cubic feet of air may be carburetted with the vapour of one gallon of the spirit which has been selected for this illustration.

The air need not be wholly saturated with vapour.

The specific gravity of this spirit is 0.655 as com-

pared with water and its composition $C_{11}H_{26}$ * that is to say, 1 ton of the spirit contains 1607 lbs. of carbon and 633 lbs. of hydrogen.

260,636
cubic feet
of inflam-
mable air
obtainable
from 1 ton
of petro-
leum.

If it be desired so to carburet the air as to obtain a pale blue flame and to mix 6 parts by weight of carbon with 8 parts of oxygen, mixing the hydrogen at the same time with half the quantity of oxygen which it would require for complete combustion, then the 1607 lbs. of carbon would require to be mixed with 2142.666 lbs. of oxygen, or 9642 lbs. of atmospheric air; and the 633 lbs. of hydrogen would require 2532 lbs. of oxygen, or 11,394 lbs. of air. One ton of the spirit may thus be made to combine with 21,036 lbs., or 260,636 cubic feet of air, and will produce that quantity of an inflammable gas; or one gallon weighing 6.55 lbs. will produce 762 cubic feet. This is more than twenty-six times the quantity of gas obtainable from one ton of coal.

When heavier oils are used with higher boiling points, the degree to which the temperature of the oil must be raised will be in proportion to the difference in their temperature of ebullition. For example, an oil which boils at 212° Fahr. will give off at 118° Fahr. the same quantity of vapour that is obtained at 32° Fahr. from the spirit we have just been examining, the boiling point of which is 126° Fahr.

* See Table A.

III.—SUPERIORITY IN CALORIFIC POWER AND IN THERMAL EFFECT OF PE- TROLEUM AND OTHER HYDROCARBON LIQUIDS OVER COAL.

By the combustion of the air and vapour mixed approximately in the proportion just mentioned, all smoke and soot and other effects of the incomplete combustion of fuel are entirely avoided, the whole of the oxygen contained in the air is utilized, and a very small additional quantity of air supplied at the burners or in the furnace suffices to complete the combustion and to carry off the burnt gases or products of combustion without any considerable draught being necessary. The perfect result is thus arrived at of burning the whole of the carbon contained in the liquid fuel to carbonic acid and the whole of the hydrogen to water, and all the ordinary causes of loss of heat have not even to be contended with, so that very nearly the whole of the calorific power of the fuel, amounting in the lighter oils, as may be seen by the annexed Table A, to no less than from 27,000 to 28,000 heat-units, can be practically realized, and 1 lb. of the fuel will suffice to evaporate from 27 to 28 lbs. of water, or nearly four times as much as is ordinarily evaporated in well-constructed boiler furnaces by the combustion of coal; thus establishing the first point which we undertook to demonstrate, viz. the superior calorific power of the mineral oil.*

Complete combustion obtainable with air hydrocarbon-buretted as described.

Evaporative power of petroleum.

* In 1869 M. Sainte-Claire Deville made a series of very careful experiments with fifty different specimens of heavy crude petroleum and other mineral oils, in order thoroughly to test their calorific power, using for the purpose a tubular boiler, containing

Waste of
heat in
high-tem-
perature
furnaces.

Proceeding now to the second point, it will be seen that the use of mineral oils is still more advantageous when very high temperatures are required. The causes of waste in the combustion of coal formed the subject of a careful investigation by the Royal Commission in the year 1866, and it was then shown that in working high-temperature furnaces the loss is infinitely greater even than in those used for the generation of steam; according to the statement made to the Royal Commissioners by Mr. C. W. Siemens, it amounts to no less than nineteen-twentieths of the heat generated from the fuel.

This is in a great measure due to the very high temperature (sometimes as much as 3000° Fahr.) at which the air and products of combustion escape into the chimney; which loss, as was shown by Mr. C. W. Siemens, can be greatly diminished, if not entirely avoided, by using gas and his regenerative furnaces,

about 110 gallons of water. These heavier oils differ from the lighter descriptions of petroleum, the composition of which was determined by MM. Pelouze and Cahours, in that they contain a larger proportionate quantity of carbon and less hydrogen, and the average composition of the American specimens examined by M. Sainte-Claire Deville is shown to have been 84·5 per cent. of carbon, with 14 per cent. of hydrogen, and about 1·5 per cent. of oxygen. Their boiling point is also much higher, and the amount of evaporation obtained from them averaged about 21 lbs. of water to 1 lb. of oil. This result is as nearly as possible in accordance with the theoretical value of their combined constituents, reckoning the evaporative power of carbon at 15 and that of hydrogen at 64 lbs.

Table B shows M. Sainte-Claire Deville's results, as published in the Journal of the French Académie des Sciences.

Comparing the results in the two Tables A and B, it would appear as if the lighter (distilled) oils were mostly homologues of carburetted hydrogen, and the crude oils more similar in their composition to bi-carburetted hydrogen.

by means of which the hot products of combustion are re-utilized after they have left the furnace; and the same result could be similarly effected when using carburetted air; but there is another cause of loss due to the large quantity of products of combustion over which the caloric derivable from coal has to be distributed, which necessarily diminishes the thermal effect or temperature of the furnace.

Now Mr. Prideaux many years ago showed that in a furnace requiring 3200° Fahr. to weld iron, if the temperature generated by combustion is 3300° , the available heat capable of acting on the iron would be less than $\frac{1}{64}$ th part of the heat which is generated, because only half the excess above the temperature required by the iron can be regarded as available for the operation; whereas if the temperature of the furnace were only raised by 400° , viz. to 3700° , this would allow of $\frac{1}{8}$ th of the heat entering the iron, thus exhibiting the singular fact that an addition to the temperature of the furnace only amounting to $\frac{1}{8}$ th would increase the velocity of heating, and consequently the efficiency of the furnace at the crisis of welding four-fold.

The temperature of a furnace heated by means of carburetted air would, however, be very nearly double that obtainable with coal, or, keeping to the figures in the above illustration, would be raised, say from 3300° to 4900° Fahr., for the simple reason that the products of combustion would, as we have seen above, be diminished to very little more than one-half of those which are produced by the combustion of coal. Instead of only $\frac{1}{64}$ th part of the heat in the welding furnace being

Waste of heat occasioned by the low thermal effect obtainable with coal.

Increased thermal effect obtainable in a furnace by using hydrocarburetted air.

available, this would allow of $\frac{1}{4}$ th of the total heat generated entering the iron. The use of petroleum in the manner described would therefore multiply many times the efficiency of, and consequently the economy of fuel in, reverberatory and other metallurgical furnaces whenever high temperatures are required. So our second point is also established.

Mr. Menelaus' opinion of the advantages of gas as fuel.

The use of gaseous fuel has also many other collateral advantages. Mr. Menelaus, the manager of the Dowlais Iron Works, when examined by the afore-said Royal Commissioners expressed himself in the following terms in favour of gas in preference to coal:—

"The present plan of burning fuel is very barbarous indeed. In puddling you have not anything like the proper conditions under which the grate ought to be for burning fuel economically. Added to this you have continual carelessness. You can only get perfect combustion where you have high skill and great care, and with 150 puddling furnaces as we have, it is impossible to arrive at anything like perfection. If you use gas fuel you have fewer skilled men to deal with, and the management of a gas furnace is very much simpler than the management of a grate; it does not entail any labour; and where you have to combine high skill and hard work you very rarely get the work well done. I think the great advantage of Siemens' plan is that you get perfect combustion with certainty and ease, and you regenerate nearly the whole of the heat which you now send up the chimney."

In the course of a lecture delivered before the Society of Arts, upon "Carbon, &c.," by Professor Barff, and

published in the Journal of that Society on the 9th of October, 1874, the lecturer expressed himself as follows on the injurious effects of *sulphur* in coal when used in the manufacture of iron: "We know perfectly well that, although the ironmaster may select his iron ores as free from pyrites as possible, if he use coal containing sulphur, sulphur will be present in the iron—and it is a most injurious substance to have in iron; so that the presence of sulphur in iron, as regards arts and manufactures, is one of considerable importance; and it holds out to you who have inventive genius the desirability of turning your attention, having made yourselves sure upon the scientific part of the question, to the discovery of means by which sulphur can be eliminated from fuel. There is a fine opening to anyone, if he can succeed in doing that, for making a gigantic fortune."

Now it need scarcely be mentioned that the carburated air is entirely free from all traces of sulphur, since none is ever found in petroleum; and this is unquestionably another of its great advantages.

Again, Professor M. Rankine, in an admirable paper "On the Economy of Fuel, comprising Mineral Oils,"* sums up his comparison of liquid and solid fuel in the following terms:—

Professor
Macquorn
Rankine on
the advantages of
liquid fuel.

"In conclusion I may make the following observations on what we may look forward to as the probable result of the introduction of such classes of fuel as mineral oil as substitutes for coal. Coal is a very complex kind of fuel. To ensure the best pos-

* Published in the Journal of the Royal United Service Institution, vol. xi., 1867.

sible economy in the use of it requires the fulfilment of many different conditions, some of which conflict with each other. We have to burn fixed carbon, and we have to burn the gas which is disengaged from the coal. We may burn one very efficiently and not burn the other. It is extremely difficult to manage the introduction of air so that there shall be at once no risk of a deficiency of air, which causes imperfect combustion and gives bad economy in one way; or a surplus of air which carries heat to waste up the chimney, and causes bad economy in another way. On the one hand, we are exposed to the risk, from any little fault of construction or management of the furnaces, of the hydrogen going off unburned, and of its carrying off a large portion of the carbon unburned also. On the other hand, we are exposed to the risk of solid carbon being imperfectly burned and going off as carbonic oxide. The contrivances for diminishing the causes of waste are somewhat difficult and complex to apply in practice; and, above all, too much depends upon the skill of the fireman or stoker. We may say almost everything depends upon the way the furnace is managed. The very best furnaces, the very best boilers that were ever contrived, may be made extremely wasteful by a careless stoker.

“On the other hand, in using mineral oils we are somewhat in the position of the chemist who has got a good burner for burning coal gas. We have still to contrive a suitable apparatus for introducing that oil into the furnace *in such a way that it shall be thoroughly mixed with air*—whether in the state of *vapour*, or in the state of fine spray, with or without the assistance

of some porous substance to act as a wick. A steam jet seems to be the most efficient apparatus for that purpose. Then if our apparatus is properly contrived and properly constructed, and works in the right manner and produces complete combustion at first, there is no reason to suppose that it will ever act badly if treated with ordinary care.

"It would seem to be no difficult matter with fuel of that sort to reduce the waste of heat through imperfect combustion to nothing, and the waste of heat through hot gases going up the chimney to something very small indeed. In fact, such an efficiency as 90 per cent. of the total evaporative power being realized, instead of being a very extraordinary thing, may be looked for as a very ordinary thing; so that, taking the theoretical evaporative power of some hydrocarbon compounds at $22\frac{1}{2}$, we ought not to be surprised that even with rude apparatus, in a merely experimental state, we should already get an evaporation of nineteen or twenty times the weight of the fuel—say nineteen, at all events. I believe that has been realized in experiments that have been made and that are now being continued."

It will be seen by the annexed Table A that the theoretical evaporative power of the different qualities of petroleum classified by Messrs. Pelouze and Cahours reaches as high as from $27\cdot27$ to $28\cdot40$.

With regard to the question of how the carburetted air can be best applied in practice to the heating of furnaces, there will undoubtedly be much variety of opinion, and there is no doubt of its being applicable in a great variety of ways.

Siemens'
"regenera-
tive"
furnace.

The gas furnaces alluded to by Mr. Menelaus are well known, and are constructed on Mr. C. W. Siemens' "regenerative" system. This system is based upon the principle of decomposing the fuel into its gaseous elements outside of, and at a distance from, the furnace, and then introducing them into the furnace simultaneously with, but separately from, the air necessary for their combustion. It is by adopting this process that Mr. Siemens is enabled to send both the air and the gas into the furnace with a high temperature derived from the utilization of the hot products of combustion by means of which his regenerator is heated, so that the heat is gradually accumulated, and may be increased almost indefinitely. Admittedly Mr. Siemens' process is one of the greatest, if not the greatest, advance in metallurgy which has been made in recent times, and it ensures a very considerable economy in the consumption of fuel. For example, it is estimated by Mr. Siemens that in puddling grey iron the consumption of coal is reduced from 24 or 25 cwt. to from 15 to 16 cwt.; in reheating the iron, in order to work it further, the saving is more than half, and in cost the saving is two-thirds: in melting steel the consumption is reduced from 3 tons of coke in the ordinary Sheffield process, to 12 cwt. of coal by Mr. Siemens' method; and yet his system involves an unavoidable loss of heat during the operation of reducing the coal to a gaseous condition, which is effected in the so-called "gas-producer" by a process of partial combustion of the coal. The system advocated by the author for utilizing mineral oils will be understood to be perfectly applicable to Mr. Siemens'

regenerative gas furnaces, with the additional advantage of avoiding all sacrifice of heat when producing the gas; but as these furnaces are expensive and not everywhere convenient, it will be well to describe some other ways of applying the carburetted air.

According to Mr. Prideaux,* "a stream of bi-carburetted hydrogen gas, mingled with its exact combining equivalent of atmospheric air, or fifteen times its own bulk, propelled cold from the grate and only ignited as it passed over the bridge and was in the act of entering the body of the furnace, would be the *acme of perfection* where the power of rapidly imparting intense heat is required." Now this description is, as nearly as possible, a forecast of what may be done by the means here advocated for utilizing mineral oils; but the writer has found that when heating boilers, retorts, crucibles, or other closed vessels into which the flame is not admitted, the most economical way of utilizing the carburetted air is not simply to surround the vessel by a body of flame, in which case the products of combustion will necessarily convey away a large proportion of heat as they escape rapidly to the chimney, but the vessel should be partly surrounded, or built into, a species of jacket formed of fire-bricks, or lumps of fire-clay, or large flint pebbles, with sufficient interstices to permit of a number of flames impinging upon the surface of the vessel, whilst at the same time the jacket will gradually absorb a great part of the heat from the radiation of the flames, and also from the products of combustion which would otherwise be lost, and thus, after a time, the retort or boiler will be sur-

The "acme of perfection" in a furnace.

* 'Economy of Fuel,' p. 49.

rounded by a solid mass of heat, the temperature of which may, when necessary, be raised almost indefinitely. Or a vessel, shaped like a Cornish boiler, with one or more central flues, or again a tubular boiler, may be set vertically and similarly packed with bricks, or pebbles, through which the products of combustion, rising from below, will penetrate, and after gradually heating the whole mass, may be arranged to leave the boiler at the temperature of the boiling water. By this perfectly simple arrangement the heat contained in the products of combustion, instead of being wasted can be retained in contact with the boiler and directly utilized for the production of steam, and when ultimately escaping at the temperature of the water in the boiler instead of at 600° Fahr. (which can be ensured by increasing or diminishing the depth of the bed of pebbles) they can still be usefully applied in a similar manner to the heating of the carburetted air on its way into the furnace. The same system is applicable to high-temperature furnaces; and a gas furnace which is commonly used in laboratories, and known by the name of its inventor Mr. Griffin, is somewhat similarly constructed.* The narrow space between the crucible and its plumbago shell or cover is filled with flint stones or clean washed gravel. The whole force of the blue flame derived from a mixture of gas and air strikes against the crucible, but the products of combustion are forced through the surrounding pebbles, which, as well as the crucible, in ten minutes after first lighting the gas acquire a white heat; so that, in less than

* It is described in Watts' 'Dictionary of Chemistry,' vol. ii., p. 788.

twenty minutes from first lighting, cast iron and copper have been melted.

The power of flint pebbles to abstract heat from the products of combustion is so remarkable that when about six inches of pebbles lie above the crucible, and this and the pebbles about it have been white hot for half an hour, the hand can be held over the top within a few inches of the pebbles without inconvenience. It becomes wetted with the vapour which rises from the furnace, but feels only a moderate degree of heat.

IV.—SPECIAL APPLICATIONS OF CARBURETTED AIR.

The very high temperatures obtainable with carburetted air makes such a system peculiarly applicable to many metallurgical processes, and there is no doubt that, besides the uses already alluded to of welding or melting iron and steel, it might be economically applied to the smelting of copper and of tin and lead. Under certain conditions it is probable that it might be usefully employed both for the production of iron and of steel, either direct from the ore, with or without the addition of a small quantity of charcoal, or by operating on iron in properly constructed furnaces; and, owing to the great purity of the fuel, the quality of iron obtained by the use of carburetted air would resemble charcoal iron of a superior description.

For steamships making long sea-voyages, the use of this species of fuel would have very important advantages. Even if the first cost of the oil equalled

Application to metallurgical processes.

Application to ocean steamships.

the cost of the coal now used (and it would not do so in cases where the latter has in part to be supplied at distant coaling stations, where the price is often as high as from 3*l.* to 4*l.* per ton), it would only occupy one-fourth of the space now required, and consequently there would remain available for freight-paying cargo three-fourths of the space now occupied by coal. To many owners of ocean steamers this would be equivalent to an additional net profit at the rate of from 2000*l.* to 2500*l.* per voyage, or 8000*l.* to 10,000*l.* per ship per annum.

Take, for example, one of the Royal Mail Company's steamers plying between Southampton and Central America. For the outward voyage she requires to take on board at Southampton 800 tons of steam coal, costing, say, 1000*l.*; and for the return voyage a further 600 tons at Jamaica, costing, say, 1800*l.*; total, 1400 tons, costing 2800*l.* The substitution of liquid fuel in lieu of coal would require that 200 tons should be put on board at Southampton and 150 at Jamaica, the *maximum* total cost of which, if refined oil were used, would be 3500*l.*, or, say, 700*l.* more than the coal. If crude oil were used, it would cost less than 2000*l.*

On the other hand, there would be additional space available for freight-paying cargo, on the outward voyage for 600 tons, and on the homeward voyage for 450 tons; say, together, 1050 tons. If this space were occupied by even the least profitable description of cargo, it would be worth to the Royal Mail Company at least 2500*l.* per voyage, and the saving in wages, loading coal, storage, wharfage, time, &c., would be equivalent to a further 500*l.* per voyage.

It would also make direct voyages to China and Australia from England and from American ports on the Pacific Coast quite easy of accomplishment, instead of being, as is the case at present, almost impossible, owing to the excessive quantity of coal which they require, and the excessive price which in those distant seas they are obliged to pay for it.

For use in the Navy it would be equally important. In times of war our largest ironclads, as now constructed, would never be able to cross the ocean without being surrounded by a fleet of colliers to supply them with coal. The 'Devastation,' although built as a sea-going monitor intended to cross the Atlantic in time of war, can only store coal on board for a cruise, at full speed, of from twelve to fourteen days. She might store sufficient liquid fuel to steam for fifty or sixty days at the same speed.

The carburetted air will be found to be also peculiarly applicable in operations requiring a degree of heat neither rising above nor falling below a certain range of temperature. This is frequently a matter of great consideration in distilleries and in sugar and other manufactories. As an instance of its importance in some metallurgical operations, the writer will mention what he has himself accomplished in the treatment of ores of sulphur.

Pure sulphur begins to melt at a temperature of 239° Fahr., and at 248° is converted into a perfectly limpid pale yellow liquid; but if heated much above 248°, it becomes thick and no longer fluid. Again, if heated in air to 482° Fahr., it takes fire and burns with a blue flame, being then converted into sulphurous

Application to ships of the Navy.

Superiority of carburetted air for obtaining regulated temperatures.

oxide, or it will combine with 3 atoms of oxygen and form sulphuric oxide, which, when united with 1 atom of water, forms sulphuric acid. At 824° sulphur boils, and is then converted entirely into an orange-coloured vapour, which, on being condensed, forms the valuable product called sulphur flour, or flowers.

Obtaining
sulphur
flour direct
from the
ores.

In the ore from which brimstone is made sulphur is found, in Sicily and in Spain, mechanically combined with from 50 to 80 per cent. of carbonate or sulphate of lime, from which it is extremely difficult to separate the pure sulphur without losing a great deal of it. At the temperature at which the sulphur liquefies, it can only partially be separated from the matrix, to which it adheres like water to a sponge; and the higher temperature at which it boils and can be sublimated, is difficult to reach, when the fuel used is coal or wood, in furnaces of limited size, without the risk of raising still higher the heat, in which case the carbonates and sulphates would be decomposed, and the sulphur absorbed by the lime.

In Sicily the operation of melting is rudely effected by heaping large masses of the ore together and setting fire to the surface of the heap; after it has smouldered for some months, liquid sulphur is drawn off at the bottom, in a rough and much discoloured state, with the loss of from 40 to 50 per cent. of the sulphur contained in the ore. In this condition it is sold to refiners in France and England, who, by sublimation, obtain roll sulphur and sulphur flour, in which state its value is more than doubled. Were it possible for mine-owners to sublimate it at once direct from the

ore, the quantity of sulphur obtained would be nearly double, and every hundredweight of the sulphur so obtained would be worth two of ordinary melted sulphur. This, however, has always been regarded as impossible, because of the difficulty of so graduating the temperature of a furnace as to avoid the decomposition of the carbonates and sulphates of lime.

The writer has overcome this difficulty by the use of carburetted air applied to a furnace, constructed with a number of shelves, or flat retorts, one above the other, separately heated by means of a series of flames percolating through the interstices left between fire-clay bricks and pebbles.

There is no doubt that the carburetted air could be applied to the heating of dwelling-houses. In an ordinary drawing-room grate, the cost of a steady fire burning from morning till night cannot be reckoned at less than sixpence per diem, whilst for this sum no less than twenty batswing burners could for the same period be supplied with carburetted air. If the grate were ornamentally packed with large pebbles of flint or agate, or with pieces of fire-clay, instead of with coal, it would not require as many as twenty batswing flames to keep them (and consequently the room also) throughout the day at a higher temperature than that of a coal fire, or the flames themselves might be reflected from a polished surface at the back of the grate, and would offer a superficial area of little less than a square foot of clear flame, perfectly free from smoke or soot, and capable of being instantaneously raised or lowered at the will of the occupants of the room.

Application of carburetted air to ordinary household purposes, &c.

Such a system is also adaptable to portable fireplaces,

removable from one part of a room to another, capable of being raised or lowered to any convenient height, and equally available for lighting or heating the room. It is applicable to cooking purposes, and for heating bread and biscuit ovens, &c.

Hock's
petroleum
motor.

A totally different application of petroleum as fuel, which has this year been exhibited at the International Exhibition, at South Kensington, by the Schottenring Iron and Machine Company, of Vienna, may not inappropriately be here alluded to. This is a petroleum engine, invented by Mr. Julius Hock, in which the liquid or vapour is injected by atmospheric pressure into a cylinder, which becomes the combustion chamber. The cylinder contains one permanent flame, and another intermittent gas-jet is projected into it at regular intervals, thus occasioning an intermittent series of small explosions, which act upon a suitable piston and set a fly-wheel in motion. The ignition takes place by means of a temporary current of compressed gas, inflamed, and produced by the engine itself. It is stated that the Viennese Imperial Printing Establishment has employed one of these engines for several months past. It is said to consume a quarter of a gallon of petroleum per horse-power per hour, and although rather too noisy, has the great advantage that it can be started and used at a moment's notice without any preparatory getting up of steam.

Fogarty's
machine for
making
petroleum
gas.

An American machine for producing gas from petroleum has also been exhibited by Mr. Fogarty, and is likewise a most ingenious piece of mechanism, although the impression it creates is that it would be rather too complicated for domestic use. The vapour

is generated by means of a hot gas flame applied to a retort containing petroleum, and is subsequently mixed with atmospheric air drawn by the force of the current of vapour into the pipe which conducts to the burners. 3·78 gallons of petroleum, or gasoline, are said by the exhibitor to be used to carburet 1000 cubic feet of air, which in warm weather is of course only partially saturated. Whether at low temperatures the maximum vapour tension would be exceeded or otherwise, by the absorption of this comparatively large quantity of petroleum, and consequently whether condensation is to be feared, is a doubtful question, as may be seen by reference to the remarks we shall presently have occasion to make on the subject of illuminating gas. It would in a great measure depend on the quality of spirit used, but in many respects the machine is a notable one, and it supplies apparently a gas of excellent and uniform quality. It would perhaps, with slight modifications, be well adapted to the production of carburetted air from heavy oils for heating purposes. By a simple contrivance similar to that used in the Bunsen burner, the quantity of atmospheric air mixed with the vapour can be to a certain extent regulated, which is important.

The class of vessel used by the author for carburet-
 ting is of a much simpler description. It is so constructed as to form a long and continuous channel, through a part or the whole of which the air is driven according as it is desired to saturate it with vapour more or less thoroughly. Into this vessel a small quantity of oil is poured, and the air in passing over its surface creates the evaporation which supplies itself

Description
 of the carburetting
 vessel used
 by the
 author.

with vapour. When it is necessary artificially to heat the heavier oils, this may generally be effected by submerging the carburettor in a bath of tepid water. A very small quantity of warm water is sufficient for the purpose, and its requisite temperature is very soon ascertained by the operator by watching the quality of the flame produced from the gas.

The air is driven through the carburettor into the furnace by means of a slowly revolving fan, to which motion may be given by weights, water power, or steam power, whichever may be most convenient under the special conditions of the locality where the system is applied.

The air can be easily combined with exactly that quantity of vapour which it requires in order to burn most advantageously according as it may be desired to use the product for heating or for lighting purposes; and we will now proceed to explain how it may be successfully used as illuminating gas, which was the third point above spoken of.

V. — UTILIZATION OF PETROLEUM AND OTHER MINERAL OILS FOR ILLUMINATING GAS.

The idea of utilizing liquid hydrocarbons by their conversion into vapour is not by any means new ; but it is almost entirely in reference to their application as gas for illuminating purposes that such a system has hitherto attracted attention.

Half a century ago Mr. Lowe and Mr. Donovan took out patents in reference to the use of naphtha for improving the quality of the flame of common gas. A few years later, numerous and most interesting researches were made by Mr. Mansfield, of which a full description was given by him in a paper read before the Institute of Civil Engineers, in 1849, in which he explained a method of utilizing benzole by passing a stream of atmospheric air over or through it. He pointed out that one gallon of benzole, weighing not more than 7 lbs.,* might in this way be made to yield gas equivalent in luminiferous power to about 1000 cubic feet of common coal gas, for the production of which at least 200 lbs. of coal are required, so that the expense of moving the material (freight and transport) would be as 1 to 28 in favour of benzole ; and, summing up the advantages of the process, he correctly said : " In this system of gas-lighting, neither furnaces, retorts, coolers, purifiers, nor meters are required ; the burners yield products of combustion as harmless as those evolved from the

Mansfield's
process.

* Gas made from benzole of this specific gravity would necessarily condense in the pipes at ordinary winter temperatures.

purest wax ; and in the process not a particle of coke, of tar, of dirt, or of residue of any kind is produced. Such are the characters which encourage me to hope for its introduction into libraries, drawing-rooms, and boudoirs, where London gas has failed to find admission ; into theatres, country mansions, and factories, where independence of external supply may be requisite ; into churches, lighthouses, railway stations, where gas works may be inconvenient ; and into ships, and especially into ocean steam-vessels, where it would be difficult to introduce them."

Improvements on Mansfield's process.

Since that paper was read and Mr. Mansfield's patent was taken out, hundreds of modifications and so-called improvements on his apparatus have been the subject of inventions and patents ; but, generally speaking, the apparatus employed have been too complicated to be conveniently used for the production of gas, and probably few of the inventors have sufficiently studied the principles involved to be able to counteract the small practical objections which have hitherto interfered with its general adoption.

Cooling effects of evaporation.

One of the most inveterate and constantly recurring obstacles was foreseen by Mr. Mansfield, and consists in the gradual cooling of the reservoir, occasioned by the evaporation of the liquid hydrocarbon, by the air passing over it. The formation of the vapour will be continually abstracting heat from the liquid itself, and it is requisite to supply the reservoir with as much caloric as is so abstracted, for otherwise the illuminating power of the gas diminishes in a corresponding degree. He invented a complicated contrivance to counteract this effect, involving a small flame playing constantly against the

reservoir, to which instrument he gave the name of a *thermostat*. This, however, could not fail to be a source of frequent danger, and has not answered. The untimely death of Mr. Mansfield, shortly after he had taken the subject in hand, prevented his improving on it. Other inventors have neglected to provide against this objection to the use of carburetted air, and consequently the gas that they have supplied, although burning brilliantly at first, has been found in a few hours to diminish in illuminating power. On the other hand, it has been sometimes attempted to obtain gas from mineral oils by heating them in retorts.

For example, Dr. McAdam, of Edinburgh, a year or two ago, recommended gas made from crude paraffin oil. His process consisted in allowing the oil to trickle on to or through red-hot coke, by which means he obtained a gas which, according to his own statement, in twenty-four hours lost in illuminating power on the average upwards of ten candles, and very much more when stored for a longer period, whilst the total volume of gas obtained from one gallon of oil by this plan was less than 90 cubic feet. The vapour from the oil, at that high temperature, being naturally of a very dense character, was such as must necessarily to a great extent recondense into oil when passing into the colder atmosphere of a gas-holder or of gas-pipes. Now, in order that the vapour from mineral oils should combine with air in the proper proportion to afford an illuminating gas of a permanent character, and burn with a brilliant and unaltered flame, it is necessary to avoid these two extremes of excessive heat or cold. When once the

Gas obtained from paraffin oil by a hot process.

A medium temperature necessary.

vapour has combined with the air at a given temperature it will remain so combined, and thus form a perfectly permanent gas so long as that temperature is not diminished; and as it will ordinarily happen when air is mixed with the vapour of a sufficiently volatile spirit, in the manner previously described, that it will be incompletely saturated, experience has shown that the temperature must be even sensibly diminished before any such separation can take place.

But in order that the liquid may give off sufficient vapour at very low temperatures—such as will be encountered in gas-pipes in cold weather—it is necessary that the liquid should have a very low boiling point, and this involves its being of a very light specific gravity. Owing to the cooling effect of the evaporation, the gas will always be slightly colder than the surrounding atmosphere, and in the proper regulation of this effect of evaporation consists one of the chief secrets connected with the successful impregnation of the air with hydrocarbon vapour, so as to obtain a practically permanent gas which shall burn with a flame of unvarying luminosity; for, if the vapour were obtained at a temperature sensibly higher than that of the pipes, and the air were *saturated* with the vapour, its tension, when encountering the lower temperature, would diminish, condensation would ensue, and the permanency of the gas would be destroyed. On the other hand, if the gradually increasing cold produced by the evaporation of the light spirit, which after a certain time is very great, were not counteracted, the vapour would become too thin to supply sufficient illuminating power.

When this medium condition is successfully achieved, a gas may be obtained superior in illuminating power to the best coal gas, at far less expense, and by means which may be applied with equal facility to the production of quantities suitable for five lights, or for five thousand, without any difference in the cost of the gas.

Here again it will be advisable to demonstrate that such results are entirely in accordance with scientific principles.

The successful application of carburetted air as illuminating gas is not unfrequently combated by coal-gas engineers, who found their opposition on two main issues. They object in general terms :

1st. That it cannot possibly be true that one ton of petroleum spirit will suffice to make a volume of gas of equal illuminating power to ordinary coal gas, fifteen or sixteen times as great as that produced from one ton of coal.

2ndly. That the vapour absorbed by the air would, under the ordinary conditions of gas distribution, return to its original state of liquid ; that is to say, that it would neither *store* nor *travel*.

Now, with regard to the first objection, the illuminating power of all gases is directly in proportion to the amount of carbon contained in an equal volume of each, provided that this carbon is equally well heated and burnt. The luminosity of the flame is due to the carbon particles being first brought to a state of vivid incandescence and subsequently burnt. If, therefore, it can be shown that 140,000 cubic feet of air carburetted from one ton of spirit (which is at the rate

Quantity
of illumi-
nating gas
obtainable
from 1 ton
of petro-
leum spirit.

of 409 cubic feet of air per gallon) would contain just as much carbon as an equal volume of coal gas—although the latter can only be produced by the destructive distillation of fifteen or sixteen tons of good Newcastle coal—it must be conceded that fifteen or sixteen times as much illuminating gas can be produced from one ton of petroleum spirit as from one ton of coal.

Composi-
tion of coal
gas.

But the composition of coal gas is as follows:

100 lbs. of coal gas, as supplied by the Chartered Gas Company, contain—

		Proportionate Amount of	
		Carbon.	Hydrogen.
	lbs.	lbs.	lbs.
Illuminating hydrocarbons (bi- carburetted hydrogen C_2H_2)	3.530	3.096	0.434
Marsh gas (carburetted hydro- gen CH_4)	35.260	26.445	8.815
Carbonic oxide	8.950	3.810	5.110
Hydrogen	51.800	..	51.800
Nitrogen	0.38	..	..
Oxygen	0.08	..	..
Total lbs.	100.00	33.381	66.159

Thus 100 lbs. weight of coal gas, of which the specific gravity is 0.420, and its consequent volume at 35° Fahr. = 2950 cubic feet, contain 33.381 lbs. of carbon, and 140,000 cubic feet of the same gas will contain $\frac{33.381 \times 140,000}{2950} = 1584$ lbs. of carbon.

On the other hand, petroleum spirit, the specific gravity of which is 0.655, is composed, according to Messrs. Pelouze & Cahours, of 71.74 per cent. of carbon,

and 28·26 per cent. of hydrogen ;* and following their analysis, one ton of this spirit therefore contains 1607 lbs. of carbon, or 23 lbs. in excess of the quantity requisite for supplying 140,000 cubic feet of air with absolutely the same proportionate amount of carbon as is contained in the coal gas supplied by the Chartered Gas Company. Following the analyses of some other writers, the composition of the same spirit is 83·33 per cent. of carbon to 16·67 of hydrogen ; or in one ton, 1866 lbs. of carbon, which is 282 lbs. in excess of the quantity contained in 140,000 cubic feet of coal gas.

The quantity of carbon contained in the hydro-carburetted air is greater than in coal gas.

But, again, the analysis of coal gas given above shows that by far the larger part of the carbon it contains is so combined with hydrogen and oxygen as to form marsh gas and carbonic oxide, which are usually designated as non-luminous gases ; and it may be observed that the proportion of hydrogen, carbonic oxide, marsh gas, &c. is to the illuminating hydrocarbons in the proportion of 96·47 to 3·53, whereas in air carburetted at the rate of 500 cubic feet per gallon of spirit, the proportion of air to the illuminating hydrocarbon vapour will be as 85·5 to 14·5. It is also a well-known fact that when coal gas is burnt in ordinary burners, a large proportion of the carbon escapes unconsumed, because it cannot be supplied with oxygen throughout the flame sufficiently fast for its complete consumption.† The carburetted air is, on the contrary, already mechanically mixed with a large proportion of the oxygen which is necessary for its combustion,

* See Table A.

† If used in the vicinity of a bright electric light this unconsumed carbon has the appearance of smoke, and will cast a deep shadow on a sheet of white paper.

and is consequently much more effectively heated and burnt.

These circumstances may perhaps account for the fact that, when consumed in appropriate burners, the vapour of petroleum spirit will be found to suffice for the carburetting of even a far larger quantity of air suitable for illuminating purposes than that just mentioned.

The carburetted air having a density which is in proportion to that of common coal gas as 1.82 to 0.420, it is advisable to use less pressure and larger burners; and experience has shown that 500 cubic feet of air or even more may be sufficiently carburetted by the vapour from one gallon of spirit to give a highly luminiferous flame, which will last as long in burning as 1000 cubic feet of ordinary coal gas.

The "permanency" of hydro-carburetted air scientifically demonstrated.

As regards condensation, it is not in the least surprising that the opinion we have referred to should exist, for, in point of fact, if ordinary oils or resins were used for carburetting the air, condensation must inevitably take place on the air entering the cold gas-mains, but we will proceed to show when the condensation of the carburetted air *is*, and under what circumstances it is *not*, consistent with scientific principles.

In the earliest investigations of the nature of gas, a distinction was supposed to exist between gases and vapours as being respectively permanent and condensable. "*Gas est spiritus non congelabilis*," said Van Helmont more than two centuries ago; but since those early days it has been proved that no gases are really permanent, and that great pressure or very great cold will condense them just as vapours will be condensed

under given conditions of temperature or pressure. The permanency of gas by comparison with vapours is therefore only relative, and we will presently show that there are vapours which can only be condensed and reconverted into liquids under conditions which are so rarely to be met with as to allow of their being considered to all intents and purposes incondensable, or "permanent."

As long as the space occupied by a vapour, whether it be a vacuum, or a space occupied by air or by another vapour or gas, is not filled or saturated by that vapour at its maximum tension, the vapour will follow all the laws that the more permanent gases do; it will expand or diminish in volume with any increase or decrease of temperature; and according to the law of Mariotte, the elastic force or tension of all gases and vapours at a given temperature varies inversely as their volume. This has been demonstrated experimentally up to pressures equal to 27 atmospheres. When, however, either the pressure is increased or the temperature reduced, a vapour which was in the state of non-saturation may be reduced not only to its state of maximum tension, but even to a state in which it can no longer exist as a vapour, and then it will be to such an extent condensed that a portion of it will be forced to return to the liquid state.

The application of these principles to carburetted air was recently remarked upon by Mr. T. Wills in a very lucid paper, entitled "On some Recent Processes for the Manufacture of Gas for Illuminating Purposes," for which he obtained a silver medal from the Society of Arts. Illustrating his argument by the case of

aqueous vapour which always exists in greater or less quantity diffused through the air, although always in the form of vapour, yet which, on a sufficient reduction of temperature, is capable of once more assuming the liquid state, he expressed himself as follows: "A vapour of any hydrocarbon whatever will, whether it exists by itself or whether it be diffused through another gas or gases, always be such a vapour, and will invariably exhibit the properties characteristic of it. . . . If a given space, filled either with air or other gas, contain a quantity of vapour at its maximum tension, that space will be saturated with such vapour, and it will be found impossible to cause it to hold ever so slight a quantity in excess of that already existing . . . the medium in which the vapour is diffused has no effect whatever upon the quantity so diffused; a vacuum, or equal volumes of all gases or air, taking up the same quantity of the vapour of any liquid." On the other hand, so long as that space is unsaturated by the vapour, and the vapour has not reached its maximum tension, it can no more condense than the air itself. It will be in all respects practically a "permanent gas," and it should be added that when different elastic fluids have once diffused themselves uniformly through one another, they never separate again according to their different specific gravities, for however long a time the mixture may be left at rest.

The determination of whether the vapour of a hydrocarbon liquid will continue as a vapour when absorbed by the air, or whether it will condense on the temperature of the mixture being lowered, is therefore a matter subject to mathematical calculation: it depends upon

the degree of tension or elastic force of the vapour when so absorbed, and this will vary with the boiling point of the liquid and with the temperature of the mixed air and vapour.

An ordinary oil, boiling at a high temperature, will not supply a sufficiency of vapour at low temperatures to confer adequate inflammability and luminosity on the mixture. A spirit, such as we have before alluded to, the boiling point of which is 126° Fahr., will, on the contrary, supply sufficient vapour for the purpose even at temperatures far below the freezing point of water, and these two assertions are susceptible of demonstration as follows:—

Octyl, the fifth of the petroleum oils on the annexed Table A, boils at 248° Fahr., the density of its vapour at that temperature is 4·009, and one gallon of the liquid weighs 7·26 lbs. Now in order to be able to carburet 500 cubic feet of air with the vapour of one gallon of this liquid, or 68·87 cubic feet with 1 lb. in weight of vapour, it is necessary that the density of the vapour should be reduced from 4·009 to

$$\frac{1 \text{ lb. air}}{1 \text{ lb. vapour}} = \frac{12 \cdot 39}{68 \cdot 87} = 0 \cdot 18,$$

and the tension of the vapour at boiling point being 29·92, we have $29 \cdot 92 \times \frac{0 \cdot 18}{4 \cdot 009} = 1 \cdot 343 =$ tension of the vapour which is required in order to carburet 500 cubic feet of air with one gallon of the oil or spirit.

Now 1·343 will be found by the published Tables to correspond to the tension of water vapour at 88° Fahr.

and as octyl boils at $212^{\circ} + 31 = 243^{\circ}$, we find that the temperature at which the vapour from one gallon of octyl would completely saturate 500 cubic feet of air is $88^{\circ} + 31 = 119^{\circ}$ Fahr., and this is the minimum temperature at which the vapour could remain as such. At any temperature below 119° Fahr. the vapour would condense, or, in other words, an oil of which the boiling point is 243° Fahr., is wholly inapplicable to the carbureting of air for purposes of illumination.

But, on the other hand, let us now apply the same calculation to the petroleum spirit, occupying the second column in Table A, this being the spirit recommended by the writer when illuminating gas is required. It boils at 126° Fahr., the density of its vapour at that temperature is 2.85, and one gallon of the liquid weighs 6.55 lbs.

In order to carburet 500 cubic feet of air with the vapour of one gallon of this liquid, or 76.33 cubic feet with 1 lb. in weight of the vapour, it is necessary that the density of the vapour should be reduced from 2.85 to $\frac{12.39}{76.336} = 0.16231$, and the tension of the vapour at its boiling point being 29.92, we have $29.92 \times \frac{0.16231}{2.85} = 1.705$ as the tension of the vapour which we require in order to carburet 500 cubic feet of air with one gallon of the oil or spirit.

Now 1.705 will be found by the Table to correspond to the tension of water vapour at 96° ; and as the spirit we are examining boils at 126° , or at 86° below the boiling point of water, we find that the tem-

perature at which the vapour contained in 500 cubic feet of air would arrive at a state of saturation would be $96 - 86 = 10^{\circ}$ Fahr., which is, therefore, the minimum temperature at which the vapour would remain as such. So that it would require that the temperature of the carburetted air or gas should be reduced to 22° below the freezing point of water before any condensation of the vapour could take place, which is practically the same as if it were a *permanent* gas.

It may be added that the quantity of vapour corresponding to a density of 0.16231 is just half that which this quality of petroleum is capable of giving off, and the air is capable of holding at a temperature of 34° Fahr., and one quarter of that which it can give off, and the air can hold, at a temperature of 60° Fahr., so that when carburetting the air at a temperature of 34° it would be necessary that it should only be half saturated, and at 60° only one quarter saturated, in order to make 500 cubic feet of carburetted air at those temperatures, which circumstance proves how necessary it is that, in any apparatus for preparing carburetted air for lighting purposes, the means should be provided for regulating the degree of saturation according to the varying temperature of the carburettors and of the seasons. An unequal absorption of vapour, unequal consumption of spirit, and unequal luminosity in the gas, would otherwise be inevitable; and yet it is remarkable that in all the numerous patents taken out in connection with the subject hardly two inventors appear to have given this important matter any consideration.

A comparison between coal gas and carburetted air establishes the superiority of the latter.

The calorific power corresponding to 1 lb. of coal gas, as supplied by the Chartered Gas Company, is 42,479 heat-units, whilst that of air, carburetted at the rate of 500 cubic feet per gallon, is only 4026 heat-units; of 1 cubic foot of coal gas it is 1272, and of the carburetted air 366 heat-units. This, when gas is used for lighting the interior of dwelling-houses, is a great advantage in favour of the carburetted air.

Coal gas, as ordinarily burnt (unless with the addition of a Bunsen burner), does not, however, give out heat to the extent indicated by its calorific power, for the products of its combustion contain a mass of unconsumed elements and other impurities, which in rooms so lighted are the cause of the vitiated state of the atmosphere, and not only blacken the ceilings and the furniture, but are also injurious to health.

Carburetted air, on the contrary, owing to its having already so large a proportion of oxygen in its composition, will be almost entirely consumed during combustion, and it contains none of the impurities, such as sulphur, &c., which are inherent to coal gas under all circumstances. It will, therefore, neither affect the health nor have any more damaging effect than wax candles or the purest oil on the furniture and ornaments of a sitting-room.

Economy of carburetted air for lighting purposes.

A comparison of the cost of the two gases is altogether in favour of the carburetted air, of which the equivalent to 1000 cubic feet of coal gas may be supplied for little more than half the usual price charged to consumers of gas in London.

The carburetted air, as was pointed out by the late Mr. Mansfield, is specially applicable to many places

where coal gas cannot easily be obtained ; for example, in country mansions, where small gas works are extremely troublesome, and coal gas will usually cost at the rate of 14s. or 15s. per 1000 cubic feet ; in factories, churches, railway stations and carriages, and also on board of ocean steamers.

The first cost of such an apparatus as that used by the writer is very insignificant.

There remains now only one point upon which it is necessary to touch before concluding these remarks upon the practical uses of carburetted air, and this is in reference to a question in which a great deal of prejudice is involved—the question of safety.

In the paper before alluded to which was read by Mr. Wills at the Society of Arts, he expressed himself on this head as follows :

“ It has often been thought that of a necessity these very volatile liquids must be much more liable to explosion than those of higher boiling points ; such, however, is not the case ; not but that it is possible to cause them to explode,* because the vapour of any combustible hydrocarbon, when mixed with that proportion of air which contains just sufficient oxygen to burn up the hydrogen and carbon, will burn throughout at once, producing thereby sudden expansion, which is nothing else than explosion ; but the conditions necessary in order to obtain this result are more difficult in the case of these heavy vapours of very volatile bodies than when using ordinary coal gas, because just above the explosive point the air and vapour

* i. e. the vapour, for the liquid itself is under no circumstances explosive.

Superiority of carburetted air for country mansions, factories, churches, railway stations and carriages, ocean steamers, &c.

The use of carburetted air is free from danger.

simply inflame and burn, while just below it inflammation will not occur at all from the presence of too small a quantity of vapour. This is contrary to the case of hydrogen gas, which explodes with ease when mixed with air in very variable proportions. The fear has been expressed that possibly, even after the complete mixture of such a heavy vapour and air, separation other than condensation to the liquid state might occur; that is to say, that a layer of heavy vapour might lie at the bottom and a layer of the lighter air at the top; but the law of the diffusion of gases, which states that gases and vapours, whatever their differences in density, will become and remain completely mixed, invariably prevents such separation, just as in the atmosphere the heavier oxygen is not found at the bottom and the lighter nitrogen at the top, but the two are found together in practically the same proportions from wherever a sample of air is obtained."

In other respects, also, there is less danger to be apprehended from the use of carburetted air than from coal gas. There is no store of the former as there is in all cases of the latter, and the moment that the current of air ceases to flow through the carburettor the supply of gas is cut off and must instantly cease. The carburettor itself is so constructed that no flame can penetrate it, and it must, on the contrary, be extinguished on entering it.

The liquid is always kept in well-closed metal vessels of limited dimensions, and when utilized on the system advocated by the writer, need never be used in the immediate proximity of flame or fire. When used for supplying country mansions with gas, one gallon

of spirit would suffice in most cases for the daily consumption, and that cannot be considered a subject of danger. Any larger quantity might be kept at a distance from the house. In the case of steamships the metal cases should be all of similar dimensions, square or oblong, so as to fit closely together, each containing say 10 gallons of liquid, or say 30 cases to 1 ton, and they should be stored in the bottom of the ship; if necessary, under water. Engines of 600 nominal horse-power will now require, say 30 cwt. of coal per hour, and from twenty-five to thirty firemen and stokers; they would require from 7 cwt. to 8 cwt. of liquid fuel, which would involve shifting and placing in their proper position forty to fifty boxes per hour, which could be done by from two to four men. The liquid would be run into the small reservoirs attached to the several carburettors, without any risk of its being spilt or wasted, or even removed from the hold, where the carburettors might be erected with free outlet to the sea for any possible leakage of liquid or vapour, at a distance from the boiler furnaces, and from the air-supplies or fans. There is absolutely no possibility of the liquid "exploding," and it is only inflammable in the same sense that spirits of wine or brandy are so. With ordinary care there need be no fear of the vapour escaping, or still less of its being set fire to; and when packed in metal boxes of small dimensions, even an accident need not occasion danger.

If employed by the Navy in times of war there would be far less danger to be feared from the breakage of a small vessel full of liquid than from the possible destruction of an engine or boiler; whilst if the store

of small metal boxes were kept properly out of reach, they could never be exposed to accidental breakage.

When employed for metallurgical or other purposes on shore, less care would be necessary when using the carburetted air than when using ordinary coal gas, which generally involves the storage of large quantities in gas-holders. There would even be less risk involved than in the use of Mr. Siemens' regenerators, which have never suggested the idea of danger. The production of the carburetted air might always be quite securely managed at a distance from the furnaces in which it was to be employed; but the writer has used it for two years in close connection with a variety of experimental furnaces and boilers without the idea of danger having ever occurred either to himself or to the workmen employed.

In one case only, when first applying it to the lighting of a large château in Belgium, a clumsy workman, whilst pouring the liquid at night into the carburettor, placed a lighted lamp close to the inlet-hole and set fire to the vapour, which occasioned a momentary blaze and some alarm, but it was easily and quickly extinguished. That is the only kind of accident at all to be feared, and when proper arrangements are made for filling the carburettors, even the most awkward manipulator may be permitted to handle the machine without its being possible for him to occasion an escape of vapour.

VI.—RECAPITULATION.

To resume, the calorific power of petroleum as compared to coal is theoretically more than double, but when burnt as a thin vapour mechanically mixed with air previous to its admission to a boiler furnace, it will practically generate four times as much steam as coal, owing to its being completely consumed, and to the diminution in volume of hot products which escape to the chimney.

For high-temperature furnaces, in which the products of combustion carry away $\frac{1}{2}$ ths of the heat generated by coal, petroleum has an incalculable superiority, because it is capable of producing a temperature nearly double that of coal, with only half the corresponding volume of products of combustion, and thus increases the efficiency of a furnace as much as sixteenfold.

Used in the manner described, liquid fuel may be entirely converted into gas which is far more cleanly and more under control than solid fuel, requiring many less firemen and stokers, and occasioning neither ashes nor smoke.

For all purposes requiring an even temperature, for obtaining heat rapidly, and for household purposes; for the generation of steam in marine boilers whenever it is important to economize space, and to substitute freight-paying merchandise in the place of a large unproductive bulk of coal; for use in many foreign countries where coal is expensive, and for the production of illuminating gas, unquestionably petroleum and other mineral oils may be very advantageously

substituted for coal, and would be more economical. Merchant vessels using petroleum could make longer voyages with greatly increased profits, and steamers of the Navy could keep the sea longer without stopping to take in coal; the labour of supplying a vessel with fuel, of stoking, removing ashes, and so forth, would be very much lessened, and consequently many less "landsmen" would be required on board.

In conclusion, we will quote the words with which the late Admiral Sir H. J. Codrington wound up a discussion relating to this same subject several years ago :—
"The efficiency of our Navy will very much depend upon the fuel we shall use in the future, and upon the way in which we shall be able to economize the use of it, or economize the space for it in stowage. Every pound of fuel we shall be able to save hereafter will be so much space gained, not merely space gained for air and so on, but space for efficiency, for the life of the ship; because her efficiency depends upon the quantity of fuel she can store. She is no man-of-war if she goes to sea devoid of fuel, and is met by an enemy with a good supply. There would be an end of her. We must also remember that all we can gain in the way of space and efficiency will enable us to carry a better armament, and to devote the space saved to other purposes, even if we do not devote it to the life of the ship, viz. the fuel she carries; for *fuel to a ship is as the air we breathe.*"

OBSERVATIONS ON THE RECENT GUN- POWDER EXPLOSION ON THE REGENT'S CANAL.

Whilst the preceding pages were in the press, the terrible gunpowder explosion occurred on the Regent's Canal, and so much has been in consequence said and written on the question of whether or not petroleum and benzoline are explosive, that some additional remarks on this subject appear to be necessary.

The liquid itself is, of course, no more explosive than spirits of wine or brandy, and this was clearly demonstrated at the Inquest by Mr. T. W. Keats, consulting chemist to the Metropolitan Board of Works, and other competent witnesses; but the vapour, like that of all kinds of oils and spirits, will take fire just as ordinary coal gas will do, if brought into contact with flame or fire.

It is true also that if combined in a closed vessel with exactly that proportionate quantity of atmospheric air as would form a *chemical* combination between the two, it would form such a mixture as would, when touched by flame, burn throughout simultaneously, or "explode." But no such explosive mixture could result from the escape of the vapour into the open air, any more than from a similar mixture of air with the vapour of any other hydrocarbon liquid, such as, for example, brandy or spirits of wine.

The arrangements of the Grand Junction Canal Company, which permitted barrels of gunpowder and leaking casks of petroleum or benzoline to be packed together for periods of many days under a tarpaulin cover, within reach of a fire, are inconsistent with the merest common sense, for the heavy vapour from the leaking benzoline would naturally accumulate and be drawn towards the fire, on reaching which the whole of the vapour would instantaneously be inflamed like any other gas, and would set fire to the general cargo. Apparently, on the occasion in question, some instants elapsed after the first flash of the burning gas before the explosion of the gunpowder occurred, and that is precisely what might be expected, for it would require a little time for the fire to penetrate through the barrel of gunpowder as far as the first grain of powder. Being confined under the tarpaulin cover, the vapour was held together and acted as a train from the fire to the gunpowder, whereas, if the cargo had been uncovered, the vapour from the leaking benzoline would probably have been diffused with the surrounding atmosphere and have escaped in a perfectly harmless condition.

The recurrence of such an incredibly careless and improper combination of circumstances need scarcely be considered as a serious cause of danger when using petroleum as fuel. Prudent rules and regulations should be established and enforced, amongst which the writer believes that, in order to prevent leakage, it is important that metal cases should be generally adopted instead of wooden casks. Barrels of gun-

powder, or guncotton, or other explosive substances, should never be stored together with petroleum or benzoline, which, although not explosive, will take fire very easily and communicate the fire to surrounding substances.

TABLE A.—CHEMICAL COMPOSITION OF PETROLEUM OILS (compiled from the Analyses by Messrs. Pelouze and Cahours).

	Amyl.	Hexyl.	Heptyl.	Octyl.	Nonyl.	Decyl.	Endecyl.	Dodecyl.	Tridecyl.	Tetradecyl.	Pentadecyl.
Elements	$C_5 H_{12}$	$C_6 H_{14}$	$C_7 H_{16}$	$C_8 H_{18}$	$C_9 H_{20}$	$C_{10} H_{22}$	$C_{11} H_{24}$	$C_{12} H_{26}$	$C_{13} H_{28}$	$C_{14} H_{30}$	$C_{15} H_{32}$
Specific gravity .. .	0.623	0.665	0.699	0.726	0.741	0.757	0.766	0.776	0.782	0.788	0.793
Boiling point .. .	86° F.	154° F.	200° F.	243° F.	279° F.	322° F.	360° F.	398° F.	422° F.	460° F.	495° F.
Specific gravity .. .	2.538	3.050	3.616	4.009	4.541	5.040	5.483	5.972	6.569	7.019	7.523
Specific gravity .. .	71.42	72.00	72.42	72.72	73.00	73.15	73.33	73.47	73.58	73.68	73.77
Carbon	28.55	28.26	27.58	27.28	27.00	26.85	26.67	26.53	26.42	26.32	26.23
Hydrogen	23.40	28.00	27.92	27.77	27.64	27.57	27.47	27.42	27.36	27.31	27.27

CALORIFIC AND EVAPORATIVE POWER calculated from the above data on the basis of Hydrogen = 62203, and Carbon (the same as if it were solid) 14544 heat-units.

Caloric power in heat-units	28,116	27,964	27,641	27,499	27,368	27,294	27,209	27,142	27,090	27,043	27,000
Evaporative power .. .	28.40	28.25	27.92	27.77	27.64	27.57	27.47	27.42	27.36	27.31	27.27

CALORIFIC AND EVAPORATIVE POWER calculated from the above data on the basis of Hydrogen = 62203, and Carbon (the same as if it were solid) 14544 heat-units.

[illegible]

CHEMICAL COMPOSITION OF COAL, COKE, WOOD, PEAT, ALCOHOL, CHARCOAL, MINERAL OILS, MARSH GAS, AND OLEFIANT GAS.

[illegible]

TABLE B.

Description and Origin of Oil. (Analysed by M. Sainte-Claire Deville.*)	Chemical Composition.	Specific Gravity at 32° F.	Calorific Power in metrical heat-units of 1 kilog. of oil.	Evapo- rative Power of 1 kilog. of oil.
1. Heavy crude petroleum from West Virginia	C. 83.5 H. 13.3 O. 3.2 C. 84.3	0.873	10,180	18.51
2. Light crude ditto ditto	H. 14.1 O. 1.6 C. 82.0	0.8412	10,223	18.60
3. Ditto ditto from Pennsylvania	H. 14.8 O. 3.2 C. 84.2	0.816	9,963	18.11
4. Heavy crude ditto from Ohio	H. 13.1 O. 2.7 C. 84.9	0.887	10,399	18.91
5. Ditto ditto from Pennsylvania	H. 13.7 O. 1.4 C. 83.4	0.886	10,672	19.40
6. American crude ditto as sold in Paris ..	H. 14.7 O. 1.9 C. 82.0	0.820	9,771	17.76
7. Heavy coal oil supplied by the Paris Gas Company (Cie. Parisienne)	H. 7.6 O.N.S.10.4 C. 84.6	1.044	8,916	16.20
8. Petroleum from Parma	H. 13.6 O. 1.8 C. 87.1	0.786	10,121	18.40
9. Ditto from Java	H. 12.0 O. 0.9 C. 83.6	0.923	10,831	19.70
10. Ditto ditto	H. 14.0 O. 2.4 C. 85.0	0.827	9,593	17.44
11. Ditto ditto	H. 11.2 O. 2.8 C. 86.9	0.972	10,183	18.51
12. Ditto from Bechelbronn (Department of the Bas-Rhin, France).. .. .	H. 11.8 O. 1.3 C. 85.7	0.912	9,708	17.75
14. Crude petroleum from Bechelbronn ..	H. 12.0 O. 2.3 C. 86.2	0.892	10,020	18.22
15. Petroleum from Schwabwiller (Depart- ment of the Bas-Rhin)	H. 13.3 O. 0.5 C. 82.2	0.861	10,458	19.01
21. Ditto from Galitzia (Ost-Gallizien) ..	H. 12.1 O. 5.7 C. 85.3	0.870	10,005	18.21
22. Ditto from West Gallizien	H. 12.6 O. 2.1 C. 80.3	0.885	10,231	18.60
39. Crude oil from Vagnas schist (Depart- ment of the Ardèche)	H. 11.5 O. 8.2 C. 79.7	0.911	9,046	16.45
40. Ditto from Autun schist	H. 11.8 O. 8.5 C. 87.1	0.870	9,950	18.11
41. Heavy oil made* from pine wood	H. 10.4 O. 2.5	0.985	10,081	18.23
42. Schist oil from the Condemine works ..	..	..	9,476	17.22
43. Heavy schist oil from M. Cogmet's works	..	..	9,654	17.55

Note.—Other crude petroleum oils, proceeding from Circassia, Wallachia, Piedmont, Zante, Canada West, and China, were also analysed by M. Sainte-Claire Deville, but their calorific power is not stated.

* Journal of the French Académie des Sciences, vol. lxvi., p. 446; and vol. lxviii., p. 686.

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